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THE VITAL RELATION OF TRAIN CONTROL TO THE VALUE OF STEAM AND ELECTRIC RAILWAY PROPERTIES.*

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THE railroads carry the life-blood of our society. They provide that circulation or communication between parts which is indispensable to the life of all organisms—physical, social, and economic. If circulation ceases, life also ceases; and the life of an organism is healthful in the same degree that the circulation is free and active.

The railroads are the arteries of our social order. To dispense with them and to depend entirely upon the smaller channels of transportation, such as wagons, motors, and, in this day of scientific farming, the tractor, would be to tax the capillaries of our body politic with the work of arteries and to result in mortal congestion. It is essential that the capacity of our system of railroads keep pace with the rapid growth of our institutions, that they may not atrophy and die.

The fact that the railroads have an importance to the social body equivalent to that of the vascular system to the human body should be enough to convince the public that it is as unwise to

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hamper and interfere with the operation of railroads as it is for a man to restrict the flow in his arteries.

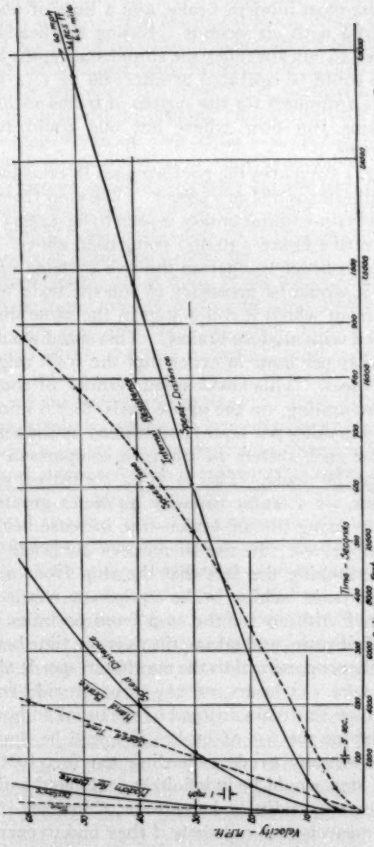
The business of the railroad is to move trains. Therefore, the value of its right-of-way properties is in direct proportion to their capacity for the movement of trains. It has been well said that time is the essence of railroading; that is, the fundamental purpose of the railroad is to save time. To increase traffic capacity involves operating at higher speeds, and at more frequent intervals, trains of a greater number of cars, with greater carrying capacity. Increased traffic capacity means a greater number of ton-miles and passenger-miles per unit of time.

It goes without saying that an increase in the number of tracks of a railroad will enlarge its capacity, and enlarge it in greater proportion than the increase in the number of tracks, for additional tracks permit the segregation of traffic according to kind, and also prevent a tie-up on one track to tie up the whole line. Also, grade and curve reductions enable the running of longer trains at higher speeds, so far as getting trains into motion and keeping them there are concerned.

But to get the maximum volume of traffic out of any *set conditions of roadway* it is necessary to employ the most improved means of train control; that is, there is a vital relation between train control and the service which railway properties can render, and this service is the measure of their value.

The relation of the wheel flange and the rail in providing *lateral* control to the movement of trains is a commonplace, and crosses the threshold into consciousness only when a broken flange puts a train into the ditch, with great loss of life and property. Similarly, the significance of longitudinal control, or, more simply stated, the ability to stop, does not receive the appreciation it merits. Naturally, were motion not imparted to a train, it would require no provision for control. To put a train into motion without adequate control would be more futile, not to mention the danger, than not to have moved the train at all.

Consider what the congestion in modern traffic would be were it necessary to remove all forms of hand and air brakes from existing equipment. Based on the results of experiments conducted on the Illinois Central Railroad by Prof. E. C. Schmidt, and confirmed by tests we have made, a passenger train stop from 60 miles per hour due to internal friction alone would require


Velocity - R.P.M.
Time - Seconds
Distance - Feet
Miles
Speed - Distance
Modern Air Brake
Hand Brake
Slack Run-in
Slack Run-out
Distance for Brake
Distance
Time
Speed
Slack Distance
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Speed Distance
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something over 30,000 feet—about six miles—as compared with 1000 feet, the stop distance for a passenger train equipped with the most modern brake, and a time of about 14 minutes, as compared with 20 seconds. Basing the headway upon the time required to run six times the stop distance, the modern trains with brakes could be operated at intervals of 1.14 minutes, compared with 34.1 minutes for the system of trains without brakes; that is, 30 trains run now where but one could run, lacking brake equipment.

Fig. 1 compares the performance in retardation of trains with and without control equipment. The stop from 60 miles per hour for the train without brakes is seen to be 34,825 feet instead of the conservative figure (30,000 feet) used above.

But in order to operate the two systems of trains with equal safety it would be necessary to run the train without brakes at a speed from which it could stop in the same distance as the train equipped with modern brakes. This speed would have to be about nine miles per hour in order that the train might come to a stop in 1000 feet. This lower speed permits, of course, reduced headway, amounting, on the above basis, to 7.6 minutes. If now the velocity in miles per hour is multiplied by the number of trains per hour for each system of trains, a comparison of train-miles per hour can be made. This is 3150, compared with 71 train-miles per hour, or a traffic capacity 44 times greater for the system of trains using the air brake—the increase being due to that one thing alone, viz., the use of modern air brake equipment.

Overlooking the fact that the stop from nine miles per hour with the train lacking brake equipment requires 125 seconds, as compared with 20 for the stop from 60 miles per hour with the air-braked train, and taking the average time between terminals as inversely proportional to the maximum speeds above considered, it would take 133 hours, or 5½ days, to ride from New York to Chicago on this train, instead of the usual 20 hours.

Without the use of brakes it would be impossible to operate trains over any grade exceeding ten feet to the mile. At this point a stop would be indefinitely prolonged and the time between trains correspondingly increased. Consider, if you can, what it would mean to our railroads if they had to carry grade reduction to the point of having two-tenths of one per cent. as the maximum permissible grade!

And, finally, the element of flexibility, or ability to apply any part of the total range of braking effort at the desired moment, comes up for the comparison which baffles numerical illustration. It can be said, however, that the train without braking effort other than that of internal resistance has this braking effort all on all the while, and it can be modified only by applying accelerating effort. The modern air brake, on the other hand, permits all degrees or gradations, up or down, of braking effort, from the very minimum needed to slow down or stop from low speeds to the very maximum needed in an emergency while running at high speeds. Imagine the degree of skill necessary on the part of an engineman in handling a train without brakes to "spot" baggage, a coal chute, or a water tank, involving, as it would involve, variations in grade, curves, train resistance, etc.

Comparing the effectiveness of the hand brake with that of the modern air brake, it is found on the foregoing basis that about eleven trains can be run, equipped with the latter, to every one equipped with the hand brake, the stop distances being 9000 and 1000 feet, respectively, from a speed of 60 miles per hour. Putting the two equipments on the same stop basis, viz., 1000 feet, the maximum speed permissible for the hand-braked train is 20 miles per hour, and the traffic capacity for a system of such trains is 363 train-miles per hour, as compared with the 3150 established above for the air-braked trains, or nine times less. It would take 60 hours to travel from Chicago to New York, or the distance would be virtually increased three times, viz., from 1000 to 3000 miles.

All of this is based on having a brakeman at every wheel and ready to do his part at the appointed time. In this light, it is seen that the service stopping distance would be shorter than the emergency, because in the latter the surprise, or lack of preparedness, element would lengthen the dead time obtaining at the beginning before the brakes could be started into action.

Picture the number of brakemen which would be required to handle our modern passenger, and particularly our modern freight, trains; and also the lack in flexibility afforded the engineman in making stops at desired points, and in controlling a train down a mountain whereon it is necessary to make allowances for changes in grade, curvature, and other local conditions. There can be no team work equal to that possible in one player only—no coördi-

nation like that found in a single man—and the control of a train concentrated in one person, with the corresponding concentration of responsibility, is the ideal condition, due regard being given, of course, to any and all practical provisions for a "watchman to watch the watchman." The fireman in the cab, the "deadman's" device for electric traction service, the conductor's valve on the train, and the automatic stop and cab signal are some to be properly mentioned in this connection.

Having attempted to sketch briefly the tremendous importance of adequate control for the movement of trains, provided by the modern air brake, to the question of traffic capacity, which is of such pressing moment to every railroad manager, it is well to turn to the financial phase of the matter. In other words, is the investment in modern brake apparatus a paying investment? Does the return warrant the expenditure?

Using American railway statistics for the year 1914, the average *per diem* mileage for each freight car is 24.5, and the average load per car, involving loaded and empty car movements, is 13.9 tons. The revenue per ton-mile—the cost to the consumer of the railroad's product—is the astonishingly low figure of 0.733 cent, a rate unequalled by any other nation on the face of the globe. The product of these three figures gives $2.50 as the daily revenue for each car. An annual depreciation and maintenance charge of 4 per cent., added to 6 per cent. for the interest on the investment, gives a total of 10 per cent., which, applied to an average cost of $40 for the air brake equipment per car, results in a daily charge for this equipment of 1.095 cents. This is but forty-four one-hundredths of one per cent. (0.44 per cent.) of the daily revenue which the brake makes possible, a revenue which, without the brake, would drop to five cents per day or less with the same ton-mile charge, instead of the above $2.50, due to the fact that the ton-mileage per car would be cut forty times; that is, it would take forty cars without the brakes to do the work of one car equipped as at present, theoretically speaking. Practically considered, it is impossible to say how much the unit costs per ton-mile would be raised if the brake were dispensed with, for the features of necessary grade reduction, lack of flexibility and safety, make it absurd to attempt an estimate.

However, using the same basis, it is found that an additional investment for brakes of 4 per cent. of the value of a car, using

$1000 for the latter, increases its capacity forty-fold. In other words, an investment of $40 corresponds to an alternative investment of 39 times $1000, or $39,000. Assuredly it requires no marked business acumen to choose between these alternatives!

It may be advanced that other countries, using brakes which do not even approximate ours in efficiency (to say nothing of the cases where automatic brakes are not used at all), are getting along; are hauling freight every day, and are keeping trains in motion pretty well generally. I wonder if they are also aware of the fact that, despite greatly reduced labor costs, the ton-mile rates elsewhere are a number of times greater than ours. This is of great concern to us, for, in the last analysis, a difference in freight rate of one dollar per ton for a certain haul may mean two or three times this amount before the bill reaches the ultimate consumer—not the shipper, but the consumer of the article shipped. And, after all, the final economic burden always rests upon the commonwealth.

In his discussion of Mr. J. S. Y. Fralich's paper on "Freight Car Brake Installation," presented before the Western Railway Club last December, Mr. W. E. Symons illustrates in a striking manner the comparative values of the air brake equipment and the life and property which it safeguards. He says:

"In estimating the value of the train (Twentieth Century, 18-hour train) with 200 passengers, on the usual legal estimate of passengers, the train and its contents would be worth $1,157,000, and the brakes on the train would be worth approximately $2255, which is a little less than two-tenths of 1 per cent. (0.195 per cent.)."

Insurance has developed wonderfully of recent years into an exact and indispensable science—an institution which wholesomely establishes more firmly every day that economic equity towards which we shall and must come some day. Did you ever consider the air brake in relation to insurance? Suppose we assume that each full train equipment mentioned by Mr. Symons makes 150 trips per year between New York and Chicago. This is a very conservative estimate, providing, as it does, ample allowance for terminal lay-overs for cleaning, maintenance, etc. The average *per diem* value of the train must then be taken at $150/365 \times \$1,157,000 = \$475,000$, as it takes approximately one day for each trip. It is difficult to say where the line should be drawn between

the insurance charges for the air brake and the service or traffic charges, because the insurance arises in the potential or *latent* power of the equipment to make an emergency stop when the necessity arises, and therefore practically all the wear and tear comes in, and should be charged to, ordinary service. Using, however, the liberal allowance of an annual charge of 4 per cent. for depreciation and maintenance and 6 per cent. for interest on the investment, the total of 10 per cent. gives a daily charge on $2255, the cost of the brake equipment, of almost 62 cents. This is 13 one-hundred-thousandths of 1 per cent. (0.00013 per cent.) of the train value—quite a remarkable insurance rate, all will agree. Even if multiplied 100 times in order to include everything involved in the operation of the train, such as signal systems, etc., it still remains an unusually low rate.

Of course, safety appliances are in the nature of preventive insurance, for in event of a wreck there is no reimbursement for the damage. It is about as difficult to exactly estimate the insurance value of the air brake to transportation by rail as it is to estimate that of the compass to transportation by water. It may seem startling to liken the worth of the air brake to that of the compass, but it is true that each is indispensable in its own service. And it may be even more startling to say that the brake is of greater value than the compass. This is not so extreme, however, when one reflects that practically all the tonnage handled by water is also handled by rail, and that much tonnage is carried by rail which has nothing to do with water shipment. In other words, transportation by rail is the more important because there is more of it.

The hazard for transportation by rail calls for a rate of about 1.25 per cent. in the insurance world. The better insurance comparison then would be to compare this with the rate which would be demanded in event that all railway equipment were stripped of its air brake apparatus. The rate would jump so high and to such an uncertain figure that in all likelihood no insurance company would be willing even to consider such a proposition.

Up to this point the most extreme conditions have been contrasted in order that the present stage of railway science may be measured as nearly as possible on an absolute scale. All intermediate degrees of comparison may be had according to the development stages which are compared. To provide for the making of comparisons in greater detail and to facilitate an accu-

rate analysis of all the factors and their limitations for maximum traffic capacity an outline has been prepared which the subsequent portion of the paper will follow.

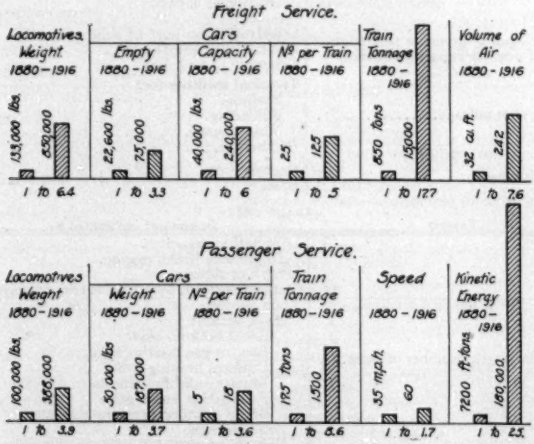
FIG. 2.

COMPARISON OF RAILROAD OPERATING CONDITIONS.

1880 – 1916.

Freight Service	1880	1916
Locomotives - lbs	133,000	650,000
Cars - lbs.	22,600	75,000
Capacity	40,000	240,000
Nº per train	25	125
Train tonnage	850	15,000
Volume of air - cu. ft.	32	242

Passenger Service	1880	1916
Locomotives - lbs.	100,000	365,000
Cars - lbs.	50,000	187,000
Nº per train	5	18
Train tonnage	175	1300
Speed - m.p.h.	35	60
Kinetic energy, ft-tons	7200	180,000



Operating conditions in 1880 differed quite materially from those of to-day. New problems require new solutions. To stop a modern passenger car from 65 m. p. h. in 25 seconds requires 1920 brake horse-power and certainly brake apparatus improved over that used on the coach of 1880 to give 149 brake horse-power for a corresponding stop from 35 m. p. h.

Before examining this outline, first consider briefly some of the changes that have occurred in operating conditions on our railroads. The contrast between conditions obtaining in 1880 and those now demanding ever more and more careful and scientific consideration is graphically portrayed in Fig. 2.

The outline for the balance of the paper now follows:

TRAFFIC CAPACITY FACTORS AND THEIR LIMITATIONS FOR MAXIMUM TRAFFIC ON STEAM AND ELECTRIC RAILWAYS. RIGHT-OF-WAY CONDITIONS CONSTANT.

CAR UNIT

Factors	Determined and limited by
Car capacity	Length of car: Clearances on curves. Width: Clearances. Height: Clearances. Weight: Rails and road-bed. Bridges. Contrast between empty and loaded weight—dead weight per ton of lading. Volume of air for control. Brake shoe duty. Draft gear capacity.
Car loading (average percentage of possible capacity realized)	Coöperation on part of shippers. Reduction of empty haul. Grouping of l.c.l. lots.
Per diem mileage	Terminal facilities for: Loading. Unloading. Maintenance. Demurrage.
Maintenance	Organization. Cost.

TRAIN UNIT

Factors	Determined and limited by
Train length (number of cars)	Locomotive capacity: Single shoe brake rigging. Length of sidings. Station platform length—electric railways. Train control: Slack action: Serial brake action. Electro-pneumatic brake. Uniform braking ratio. Impact—slid flat wheels. Foundation brake gear. Brake cylinder pressure regulator. Grade service. Volume of air: Release of brakes. Draft gear capacity.
Time of station stops	Car door arrangement and capacity for ingress and egress. Station arrangement. Local conditions as to number of passengers to load or unload. Picking up and setting out cars: Making up trains in rapid transit service. Automatic car, air and electric couplers.

TRAIN UNIT—*Continued*

Factors	Determined and limited by
Delays to trains	Terminal facilities: Trains getting into or out of yards. Defective or inadequate equipment.
Acceleration	Locomotive equipment—steam railways. Motor equipment—electric railways: Line-voltage regulation. Regenerative braking. Selective relays for empty and loaded conditions of motor car. Number of motors and trailers in train. Train resistances: Foundation brake gear. Grade.
Maximum speed	Acceleration. Station spacing. Retardation: Electro-pneumatic brake. Grade: Running control. Stops. Curves.
Retardation	Maximum speed. Weight of car: Volumes of air. Brake shoe duty. Difference between empty and loaded condition. Foundation brake gear. Number of cars—shocks due to serial brake action. Air brake equipment. Rail conditions. Regenerative braking.

SYSTEM OF TRAINS

Factors	Determined and limited by
Headway or spacing of trains	Safety: Retardation. Maximum speed. Installation and characteristics of signal apparatus. Acceleration. Length of train. Time of station stops. Speed control devices. Local roadway conditions: Station spacing. Curves. Grades. Interlocking plants. Bridges. Junctions, etc.

This outline is grouped according to the car unit, the train unit, and the system of trains.

THE CAR UNIT.

The part the car unit plays in deciding maximum traffic capacity depends upon: 1st, what it can carry; 2nd, the extent to which this total lading is realized during all movements of the car; 3rd, the daily mileage the car makes; and 4th, the condition in which it is maintained.

CAR CAPACITY.

The length, width, and height of the car govern the load it can transport, and these in turn combine to establish the total weight of the car. Right-of-way clearances limit all these dimensions.

Clearance limitations on curves dictate as to the length of the car. If the distance between truck center plates is increased, the center of the car on the inside of the curve approaches the clearance limit set for way structures. If the length, or overhang, beyond the center plates is added to, the danger of fouling comes on the outside of curves and the additional requirement arises that the couplers must have increased swing. This in turn means that new equipment will not couple satisfactorily with the old, so far as operation on curves is concerned. The new 67-foot cars for the New York Municipal Railway probably represent the maximum for electric traction service. Pullman cars have come to a length of 82 feet from the 50-foot passenger coach of 1880. The freight car has more severe conditions under which to operate in the way of sharp curves on industrial sidings, and 44 feet mark its limit—which, however, contrasts well with the 28-foot car of 35 years ago.

The width and height of all vehicles must, of course, conform to tunnels, bridges, and various road structures. Right here the reminder may be made of how simple many problems would be if we could only start anew without having to conform to old limitations—such as introducing the six-foot gauge, with clearances to provide for the future development of centuries, and all things to correspond. The most difficult problem the railway engineer has to solve is the one of interchange and conformity with existing equipment and conditions.

The weight of rolling stock can be no greater than the rails and supporting road-bed and bridges will warrant. The advent of heavy motive power in the way of Mallet, Sante Fé, Mountain,

Mikado, and other types of locomotives has brought about the strengthening and replacement of bridges and the laying of heavier rail. If an average axle load of 65,000 pounds (which ranges far above and below this, due to the effect of reciprocating parts) is permitted for a locomotive, it would certainly seem that 50,000 pounds could be permitted for a freight car where low speeds and the lack of need for riding qualities do not introduce other considerations. As a matter of fact, a railroad in the Southeast is contemplating the use of freight cars which when loaded will have an axle load of about 53,000 pounds. Of course, the tax a load imposes depends upon its frequency as well as its quantity, and therefore it is to be expected that a train of heavy axle loads would more severely burden the rail than a train with the great axle load on the locomotive only. The rail is the limiting factor for wheel loads, and it has been nip and tuck for the makers of steel rails to keep pace with the recent increases in wheel loads. The bridge is the limiting factor for the total weight of vehicle, and it must be remembered that a bridge strengthened to sustain successfully a single Mallet locomotive and cars of the usual weight might not be able to handle two or three locomotives together, or a locomotive and a train of cars each of which approaches the weight of a locomotive.

The freight cars above mentioned will weigh about 315,000 pounds loaded, which is the weight of our "largest" locomotives of a few years ago. The lading capacity is to be 245,000 pounds, which makes the ratio between the loaded and empty weights 4.5, or, viewed in another way, the dead weight per ton of lading is 571 pounds. For the 40,000-pound car of 80,000 pounds capacity, hailed as the latest word but a few years ago, the ratio of loaded to empty weight is but three; that is, there are 1000 pounds of dead weight for every ton of lading.

This decrease in dead weight with relation to lading capacity and also the greatly increased total capacity of the modern freight car display a significant trend in the reduction of unit costs on the part of our more and more efficient American railways. It also displays an operating condition correspondingly difficult, for the contrast between the empty and loaded weight has become so great that former brake apparatus—fully able to care for the wide range of operation through which it has served so long—has now become quite inadequate. A curious inconsistency is encountered in the

expectations some people have concerning the permanence and range of brake equipment, designed for operating conditions of 20 years ago, to continue with unchanging efficiency, and in their unquestioning discard for all time of the wooden underframe and the draft gear of archaic capacity.

The braking ratio for a brake installation is defined as the nominal relation between the brake shoe pressure, equal on each wheel, and the weight each wheel imposes upon the rail. If all wheels are not braked, or not braked equally, it is taken as the relation between the sum of all brake shoe pressures and the total weight of the car.

The "single capacity" brake is the one most generally found in railroad service to-day. It is one in which a constant braking force is used for all conditions of car loading, which results in a widely varying braking ratio. If a freight car is braked at 60 per cent. of its empty weight, on a cylinder pressure of 50 pounds, and the ratio of loaded to empty weight is three to one, the braking ratio for the loaded car becomes 60/3, or 20 per cent., the cylinder pressure basis still remaining 50 pounds. With a loaded to empty car weight ratio of 4.5 to 1, the loaded car braking ratio drops to 60/4.5, or 13.3 per cent. The brake installation must base the braking ratio on the empty weight of the car, and not higher than 60 per cent. Otherwise, if this 60 per cent. were based upon the loaded weight, the empty car braking ratio would be raised to a point prohibitive because of the far more violent running of slack and the slid flat wheels it would produce in long trains.

This greatly lowered braking ratio for the loaded freight car means two things: *First*, it means that trains of such cars cannot be controlled down a great many of our main line—to say nothing of our branch line—grades without resorting to either greatly restricted train lengths, the operation of empty cars in the train in order to provide the additional braking effort needed, or the use of an empty and load brake which maintains a more nearly constant braking ratio by varying the braking forces in accordance with the loading of the car. *Second*, it means that violent slack action in trains of loaded cars mixed with empties is much more certain to occur, with its inevitable damage to lading and equipment. For slack action arises in and is proportional to the variation in retardation between the different cars in a train, and

the retardation of each car is a direct function of its effective braking ratio.

The increased total weight of each vehicle is also of great significance here. Many ask why it is that to-day shocks in train operation occur with the magnitude and frequency unknown a few years back. For the same velocity difference between two cars in a train the severity of impact will depend directly upon the car weights—the heavier the cars the greater the impact. Other things being equal, the 70,000-pound car will give almost twice the shock obtaining with the 40,000-pound car. This is a partial answer to the question. The balance is found in increased velocity differences due to greater train lengths, which will be discussed under "Train Length and Serial Brake Action."

The new motor cars for the New York Municipal Railway are built to accommodate 260 passengers, making an increase of 35,000 pounds from the empty weight of 85,000 to 120,000 pounds loaded. This represents a loaded to empty weight ratio of 1.41—quite insignificant when compared with the ratios found in freight service. But in a municipality like New York trains are run "on the second," and it is essential, for the sake of maximum traffic volume, to have retardation at all times independent of the condition of car loading, and, of course, an empty and load brake is required. This is quite apart from the questions of control on grades and slack action in trains, because the weight ratio is so small as to render the former negligible and the electro-pneumatic brake circumvents any difficulty from the latter.

The empty and load brake equipment for these motor cars is so arranged that a constant braking ratio is had for all conditions of car loading, and brake flexibility is also maintained; which is the ability to graduate braking effort on or off in any desired series of steps between maximum and minimum. This is the ideal operation, but the apparatus necessary to obtain this highly desirable result is, at the present stage of the air brake art, a refinement quite out of keeping with the features of modern freight service. The difference between the empty and loaded weight of the steam road passenger coach is so comparatively slight that demands are not encountered similar to those of very dense interurban traffic..

In this connection, viz., the relation of live load to dead weight, digress for a moment to consider the comparative transportation revenues per ton-mile for passenger and for freight service. The

average capacity for all freight cars is about 40 tons (39 tons in 1914), and the average light weight probably 20 tons, or one-half the capacity. This makes the actual ton-mile rate for the total weight $40/60 \times 0.733$ cent (the net ton-mile rate for 1914), or 0.49 cent. In passenger service, on the other hand, this rate is 0.31 cent per ton-mile—determined by estimating a load of 100 persons on a seven-car train which weighs 735 tons complete, and a passenger-mile rate of 2¼ cents. Thus the passenger rate is but thirty-one forty-ninths, or 63 per cent. of the freight rate, despite the fact that the cost of handling passenger trains is far in excess of that for freight trains, due to fast schedules and the many conveniences demanded by the travelling public.

In the passenger empty and load brake the selective mechanism is thrown into engagement by the opening of the car doors. Before the car doors are shut passengers have been discharged and taken on, and the car loading is that under which operation will take place until the next stop is made. Closing the car doors disengages the selective mechanism to save it from wear and tear and from cutting in and out due to inequalities of track. One portion of this device is attached to that part of the truck which keeps it at a constant distance from the rails. The other portions are connected to the car body, and relative motion between the two—a function of the movement of the truck springs and, therefore, of the car weight—provides that base for the variation of volumes and valves which gives the desired result. This device also operates selective relays which provide a current supply to the motors so proportioned to the weight of the car that acceleration, as well as retardation, is constant, irrespective of the condition of car loading.

Without this means for providing uniform retardation the headway and schedule of trains, to the extent that they are dependent upon retardation, would be impaired 40 per cent. during loaded car movements—which, of course, constitute the critical phase of train operation.

The empty and load brake for freight service employs two distinct braking forces, due to the operation of one or of two brake cylinders during brake applications. The full service braking force obtained with the one cylinder is 60 per cent. of the empty weight of the car, as in the case of the single capacity brake. It is used with the empty and partially loaded car. But when the

car is loaded one-half or more the second brake cylinder is cut into action to assist the first, making the total braking force 40 per cent. of the weight of the fully loaded car, instead of the 13 or 15 per cent. with the single capacity brake. Where the situation permits it is most desirable, for the sake of uniformity, to use a braking ratio of 40 per cent. for both the empty and loaded car. This braking ratio provides ample control on grades; does away with the slack action due to differences in braking ratio through the train, and minimizes the effect of serial brake action in causing the running of slack, as will be shown in the discussion on "Train Length."

Increased car weights have called for larger brake cylinders and larger reservoirs, the increased volumes of which in turn have taxed the ability of the air-handling devices to conform to the time limits required for proper train operation. Compare the 10-inch equipment of the 50,000-pound passenger car of 1880 and its auxiliary reservoir volume of 2500 cubic inches with the modern Pullman requiring two auxiliary and two supplementary reservoir volumes aggregating 52,000 cubic inches. When it is remembered that the brake pipe which connects the equipments throughout the train has not been increased in size, the need for air brake devices of a design which will not overtax the capacity of the brake pipe to supply air from the locomotive becomes increasingly significant. The empty and load freight brake cuts down the air requirements for train control to one-half that now required by the equipment in most general use. This is equivalent to a valve gear on a locomotive which would do the same work as the existing type with a demand on the boiler for only one-half the steam now required.

The eight-wheeled coach of 1880 had as many brake shoes through which to dissipate the kinetic energy of the moving trains of that time as the eight-wheeled coach of to-day. But the weight of the coach has since more than doubled, thereby doubling the horse-power or duty of each brake shoe. Speeds have also increased, which means that brake shoe duty has increased as the square of the speed. Contrasting the 50,000-pound coach of 1880, running at 35 miles per hour, with the 150,000-pound Pullman of to-day, running at 65 miles per hour, the horse-power required to effect a stop in 25 seconds is 149, as compared with 1540, or, dividing this total by the number of shoes in each case, the duty

for each shoe, formerly 18.6 horse-power, has become 128.3 horse-power, or 6.9 times greater. Is there any wonder in the need for an efficient type of clasp brake, which, among a number of other important advantages, employs two brake shoes per wheel, thereby halving the load per shoe and returning the shoe more nearly to the temperature at which it can do its most efficient work? Where a set of brake shoes in a certain service lasts but 10 days with the single-shoe-per-wheel type of brake gear, a full set of shoes will last with the clasp brake 28 days, instead of the 20 days to be expected with a doubled number of shoes. If worn to the thinness that halving the brake shoe load permits, the set of brake shoes will last 33 days, as compared with 10 for the single shoe brake. This points to a great possible saving in brake shoe maintenance, as well as the more obvious one of shoe material, because a car repairer can replace 10 shoes on a car in practically the same time he can replace 5 on the same car, the preparatory measures being such a great proportion of the total effort required in each case.

The capacity of a car will, or should, depend on the capacity of the draft gear to absorb shocks. Naturally, as the weight of vehicle increases the draft gear will be called upon to perform greater service when the same velocity differences are set up between cars in stopping with brake equipment of outdistanced capacity, and in starting with locomotives of greatly increased tractive effort. Of course, all the punishment will in mixed trains come on the cars and draft gears of relatively small capacity, and if, during the transition period, these are to be spared, it will be necessary to employ the most modern train control equipment.

CAR LOADING.

It is idle to provide marvellously improved carrying capacities of the car unit by employing steel construction, etc., and then not utilize it. The extent to which this full capacity is realized when loading a car is of great significance from the standpoint of operating economy. Campaigns are being waged by various railroads to awaken the shipper to the necessity for loading cars to their full capacity and thereby assist himself as well as all others to reduce car shortages. Live stock and bulky freight of small weight prevent the utilization of full capacity as do l. c. l. (less-than-carload) shipments. The latter will be grouped to better advantage

as improved systems for so doing are evolved and put into practice.

Of course, the reduction of the empty haul increases the average load for the car. With every superintendent of transportation this problem of routing cars to cut down the empty haul is a live issue.

The application of the empty and load freight brake dispenses with the hauling of empty cars back and forth over mountain grades in order to provide the necessary braking control by keeping the average tonnage per brake to the predetermined safe figure; and as mountain grades are usually the "necks of the bottle" for the flow of railroad traffic, these "necks" are restricted by every empty car used for the purpose for which it was never built; namely, that of providing adequate control for the lading of *other* cars.

Inasmuch as only 10 to 15 per cent. of the total life of a freight car is spent in actual transit, gleaning the revenue-producing ton-miles, improvement in terminal facilities are highly desirable to provide means for more promptly loading and unloading cars and for making inspection and repairs—light or heavy as facilities permit—simultaneous with the handling of lading. Demurrage charges are being more and more scientifically established to penalize carelessness and lack of coöperation on the part of shippers in needless detention of cars as storehouses.

The traffic capacity of the car unit is indissolubly involved in the ever-present problem of maintenance, and this in turn is dependent on the factors of organization and cost. In general it is true that if maintenance charges are stinted depreciation charges will jump. The ideal is, of course, that point for each where the total is a minimum and where if either one or the other is raised or lowered the sum will increase in amount. In only too many cases, unfortunately, is it true that a penny-wise and pound-foolish policy prevails in greatly reducing maintenance work and in suffering the more than proportionately increased depreciation unconsciously, because it resembles, and really is, "indirect taxation." What is not seen and not known gives small concern.

Maintenance and service are inseparable, however, even where neglected maintenance does not cause an immediate increase in depreciation. For example, to disregard a leaky brake cylinder packing leather does not mean greater depreciation of the brake apparatus; but, so far as service is concerned, the brake equipment

might as well be entirely dispensed with if the elaborate means for putting air in the cylinder are unsupported by adequate means for keeping it there.

THE TRAIN UNIT.

TRAIN LENGTH.

Needless to say, train length, or the number of cars hauled in a train, is a vital factor in the matter of maximum traffic capacity.

The maximum train length will depend on the locomotive capacity, for the available tractive effort should be such as to start a train without the necessity for the "taking of slack" so violently as to endanger on each occasion the integrity of the train. In passenger service the single-shoe-per-wheel type of foundation brake rigging is responsible for highly increased train resistances, which mark a needless loss in locomotive capacity and also in fuel and water consumption of from 30 to 35 per cent. in many cases. This was revealed by the results of the brake tests made on the Lake Shore and Michigan Southern at Toledo in 1909. The reasons for this will appear in the discussion of "Foundation Brake Rigging."

The length of sidings or passing tracks will also govern the length of trains on single-track lines, the only exception being where trains of maximum length never need to pass one another, the only "meets" of such trains being with trains of inferior lengths, where "sawing by" is resorted to. The final limiting value of the inferior train length must not be more than twice the length of the siding. In such a case, however, the "sawing by" becomes so very much involved that the practical operating limit for the inferior train length will be the siding capacity. In some respects this factor of siding length should appear under the division "System of Trains," for a single train alone considered involves no element of passing track length.

For electric railways the length of the station platform frequently determines the permissible length of trains, for obviously passengers cannot enter or alight from cars standing beyond the platform. A very important feature of the reconstruction of some of the New York subways has been the extension of station platforms to permit the running of longer trains.

Unfortunately for our reputation for statesmanship, legal limits have been established in some cases for the number of cars to be permitted in a train, but it is to be hoped that the sense of

reason and fair play among our people will soon prevail on their representatives not to apply artificial restrictions on the arteries of commerce and handicap society as a whole to just that extent.

SLACK ACTION.

But the element of train control is probably the most significant of all factors in this problem of train lengths. Consider first the question of serial brake action, or the behavior of brakes on individual cars in sequence and in relation to the train as a whole. When an ordinary pneumatic brake application is started at the front end of the train the first car is the first to experience brake action, and each car follows from the head end to the rear, according to its position in the train, the brake on the last car being the last to apply. The time between the application of the brake on the first and that on the last car is called the "time of serial action." For any given type of air brake equipment this time varies with the length of train. Therefore, when a brake application is started the first car will have had its speed reduced, before the brake applies on the last car and before the slack in the train runs in, by an amount proportional to the severity of the brake application, to the total amount of slack in the train, and to the time of serial action.

The severity of the brake application, or, in other words, the rate of retardation set up, depends upon the brake cylinder pressure realized; the basic cylinder pressure for the nominal braking ratio; the nominal braking ratio; and the efficiency factor. This may be briefly summed up in mathematical form—

$$R = \frac{p}{C} P \, ef$$

Where:

R = the retardation factor, in per cent.;
P = the nominal braking ratio, per cent., based on
C = the basic cylinder pressure for P, pounds per square inch;
p = the effective cylinder pressure, pounds per square inch;
ef = the efficiency factor.

By the retardation factor (R) is meant the relation of the actual retarding force to the total weight of the vehicle. It is a measure of the rate of retardation. A retarding factor of 100 per cent. obtains when the retarding force equals the weight of the

vehicle, or, in other words, when the retardation is equal to that due to gravity—32.2 feet per second per second, or 22 miles per hour per second.

As before noted, the nominal braking ratio (P) is the ratio between the total nominal brake shoe pressures on the wheels of the car and the weight of the car. It is a "nominal" braking ratio, because it makes no allowance for losses in the transmission of the brake cylinder force, by the multiplying, or leverage system, of the foundation brake gear, to the normal or perpendicular brake shoe pressure on each wheel.

The basic cylinder pressure (C) assumed to be in the cylinder when the braking ratio is established, is taken as the nominal pressure arising from a full service, or an emergency, brake application, according as the service braking ratio or the emergency braking ratio is in question. For the service braking ratio this pressure is 50 pounds with freight brake installations and generally 60 pounds for passenger equipments.

The actual pressure (p) realized in the cylinder depends on the brake pipe reduction made, the piston travel, and cylinder packing leakage. For the purposes of computation and comparison, it is necessary to deduct 5 pounds from this pressure, especially when it is relatively low, to give the *effective* pressure, because it will take about 5 pounds to compress all release springs and place the brake shoes against the wheels ready to "start business." For the higher cylinder pressures—35 pounds and more—this deduction may be neglected and the $e \times f$, or efficiency, factor be made to compensate for release springs, etc.; that is, for the lower pressures the efficiency factor, flexible like the cloak of charity as it is, cannot be made to cover the proportionately great sin of this initial loss. In other words, the efficiency factor cannot conveniently be made a function of cylinder pressure in addition to one of speed and type of foundation brake rigging.

The efficiency factor ($e \times f$) is the combined product of the brake rigging efficiency (e) for transmitting and multiplying the cylinder force into normal brake shoe pressure, and the coefficient of brake shoe friction (f), which is the measure of the tangential force acting on each wheel in relation to the normal brake shoe pressure. It is not possible, nor is it necessary, to separate these two factors for the purposes of computation. The combined product is the connecting link between the actual average re-

tarding force which must have been acting to effect a given stop distance obtained in actual service and the nominal brake shoe pressure determined by multiplying the brake cylinder pressure by the piston area and the leverage ratio of the brake rigging.

Now look again at the expression for the measure of, or the rate of, retardation:

$$R = \frac{p}{C} P\, ef$$

If p, P, or ef be singly or severally raised or lowered in value, R will be correspondingly raised or lowered. If C be raised, R will be lowered, and *vice versa*. Thus it will be seen that if the actual cylinder pressure (p) be high, due to a heavy brake pipe reduction having been made, or to short piston travel, the retardation will be correspondingly high; and if this pressure be low, due to a light brake pipe reduction, long piston travel, reduced auxiliary reservoir volume, or leakage, the retardation rate will also be low.

If the braking ratio (P) be high, as, for example, 80 per cent. on a freight train, the retardation set up on the head end of the train in a certain time will be twice that with the braking ratio equal to only 40 per cent., other things being the same.

And, finally, if the efficiency factor (ef) be low, as it is at high speeds, due to the variation in coefficient of shoe friction, the retardation will be low as well, and *vice versa*, for low speeds. Thus if the efficiency factor be 8 per cent. for a speed of 50 miles per hour, the retardation set up at the head end of a train will be approximately half that where the efficiency factor equals 15 per cent. for a speed of 12 miles per hour.

If the amount of slack movement between the cars in a train is increased, more time is given for the cars first experiencing brake action, or experiencing the more severe brake action, to retard before the other cars close in or pull away, as the case may be. Therefore, the velocity difference between cars will depend on the amount of slack in the train, being greater as the slack is greater, though not in direct proportion. It is easy to see that if there were no slack or possible relative movement between the cars in the train there could be no difference in velocity set up between them. Carrying this to the other extreme, it can be imagined that the slack could be so excessive that the last car in the train might be entirely stopped before the slack had closed in. Thus there

will be no shock where the slack is zero, and there will be no shock where the slack is sufficient in amount to permit all the cars to come to a stop before this slack runs in. This upper limiting value of slack necessary to avoid shock will vary with the braking characteristics (rate of retardation and time of serial action) and with the initial speed of the train. Somewhere between these limiting values of slack there will be a point at which the maximum shock can occur, all other factors but the one of slack remaining constant. This critical value of slack for maximum shock (the maximum, of course, being different for each condition) tends to become greater as the speed is higher, as the time of serial action is longer, and as the rate of retardation is less. It is obvious that as the length of train is increased, so also is the total amount of slack.

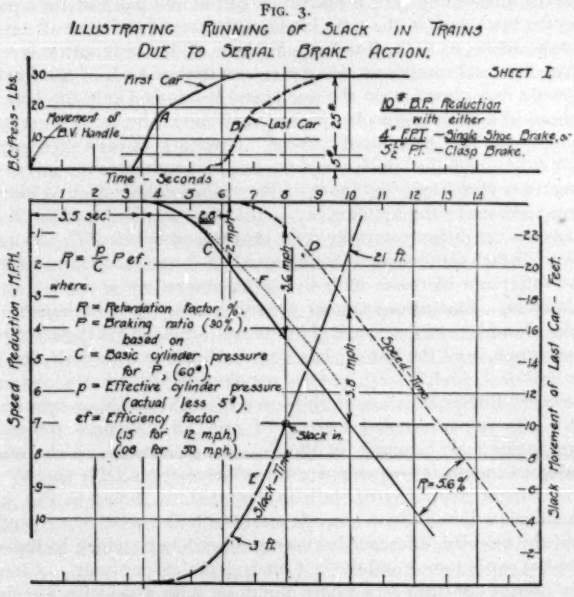
The foregoing means that in making a brake application there is a critical speed for maximum shock, due in a measure to resonance in slack surging and to the grouping of various vehicles in the train. Variations from this critical speed at the time of applying the brakes, together with favorable positions and amounts of slack, account for the fact that severe shocks do not occur with *every* brake application in service where they do appear more or less frequently.

However, the amount of slack is of no moment if the time of serial action be zero, as with the electro-pneumatic brake. Here the last brake starts to apply as soon as the first, for all the brakes go on as one. As the time of serial action is increased the dangers due to slack action also increase. Increased time of serial action means increased opportunity for greater retardation on the head end of a train before the slack closes in. It is clearly seen that the time of serial brake action is directly proportional to the length of train.

Refer to Figs. 3, 4, 5, 6, and 7 for graphical illustration of all these points. On Fig. 3, curve *A* is that of brake cylinder pressure on the first car. It shows that the pressure begins to rise at about 3.2 seconds after the brake valve handle is moved to application position, and 0.3 second later it passes the 5-pound point, at which it is assumed that the brake shoes have been brought just against the wheels. Retardation on the first car then commences, and as time continues the speed of the car is more and more reduced, as shown by curve *C*. Retardation increases in rate as

cylinder pressure builds up until the maximum is reached at a little after 6 seconds' time. The slope of curve *C* represents the rate of retardation—as the slope is steeper the retardation, or change in velocity for a certain time, is greater. Curves *B* and *D* are

FIG. 3.


ILLUSTRATING RUNNING OF SLACK IN TRAINS DUE TO SERIAL BRAKE ACTION.
SHEET I
B.C. Press - Lbs.
First Car
Movement of B.V. Handle
A
B
Last Car
10# B.P. Reduction with either 4" F.P.T. - Single Shoe Brake, or 5½" P.T. - Clasp Brake.
Time - Seconds
3.5 sec.
2.8
C
12 m.p.h.
D
21 ft.
16 m.p.h.
F
Speed - Time
3.8 m.p.h.
Slack in.
E
Slack - Time
3 ft.
R = 5.6%
Speed Reduction - M.P.H.
Slack Movement of Last Car - Feet.
R = P/C Pef.
where.
R = Retardation factor, %.
P = Braking ratio (90%), based on
C = Basic cylinder pressure for P, (60#).
p = Effective cylinder pressure (actual less 5#).
ef = Efficiency factor (.15 for 12 m.p.h) (.08 for 50 m.p.h).
Assumed Conditions:
Slack in 12 passenger cars = 10 feet. Speed = 12 m.p.h. (ef=.15)
Brake pipe reduction = 10#. L.N. air brake equipment.
4" false piston travel, or 5½" constant piston travel.

The delay in application of the last brake in a train permits the head brake to effect greater retardation than the last before the slack runs in. In general, the less the slack the less the retardation difference, and therefore the less the shock will be.

similar curves for the last car, the serial time being shown as 2.8 seconds; that is, the brake on the last car got into operation 2.8 seconds later than did the first. Curve *E* is one representing the relative, or slack, movement between the first and last car, due to the differences in retardation. This movement is equal to the

average velocity difference between the two cars multiplied by the time during which the average difference occurs.

Curves *C*, *D*, and *E* neglect the cars intervening between the first and last, and assume a condition equivalent to the removal of the intervening cars, a separation of the first and last car equal to the total slack in the train, and a retention of the time of serial brake action, as with all the cars in place. This assumption is not true to actual conditions, for the reason that as each of the intervening cars closes in on the one ahead it boosts along the bunch ahead at a speed somewhat higher than shown by curve *C*—possibly something like dotted curve *F*. However, as each successive car closes in on the bunch ahead the impact accelerates the increasing mass ahead less, and more of the sudden changing in velocity must be done by the colliding car, so that the retardation of the first car does not differ materially from that shown by curve *C*. Moreover, as each successive car collides with the bunch ahead the velocity difference increases until it is a maximum when the last car closes in. This means that as the shock runs back the bunch of cars ahead becomes increasingly solid, so far as the draft gears are concerned, until the last car has a veritable stone wall with which to collide. And, finally, as it is not known just what a certain velocity difference means in the force of an actual blow between two cars or one car and a group of cars, an allowance for discrepancies may be made in the velocity difference which it is assumed the draft gear can care for without appreciable shock.

If there be 10 feet of slack in the train, as shown in Fig. 3, this slack will be all in, 8 seconds after the brake valve movement, and the velocity difference between the head end (which includes the last car but one) and the last car is 3.6 miles per hour. After the impact the train as a whole moves on with a velocity a trifle higher than that represented by curve *C* at the instant of impact, as explained in connection with curve *F*. Curves *C* and *D* are shown heavy to the instant of impact of the last car, for 10 feet of slack. They are continued with lighter lines in order that the influences of other conditions of slack may be compared. For any actual case, the impact causes curve *D* to drop down and be merged with curve *C*, which is slightly raised. Dispensing with this geometrical parlance, this can be stated otherwise by saying that the front portion of the train and the rear car move on with the same velocity after impact, retarding together.

If the amount of slack in the train be cut down to three feet and the time of serial brake action remain unchanged, the velocity difference is seen to be but two miles per hour. With 21 feet of slack the velocity difference is 3.8 miles per hour, an amount not materially different from that for 10 feet of slack. Thus it is seen that *the less the slack in the train the less the velocity difference between the head end and rear, and, therefore, the less the shock.* However, after a certain point, about nine seconds here, when curves *C* and *D* become parallel, due to the cylinder pressures being the same on head end and rear, the velocity difference is the same, irrespective of the amount of slack. The retardation for curves *C* and *D* is 5.6 per cent. It must be remembered that where the speed is such as to permit the head end to stop before the rear end runs in, an increase in the amount of slack tends to decrease the severity of the shock—other things remaining equal—in that more time is afforded the rear end for retardation. This was pointed out in a foregoing discussion.

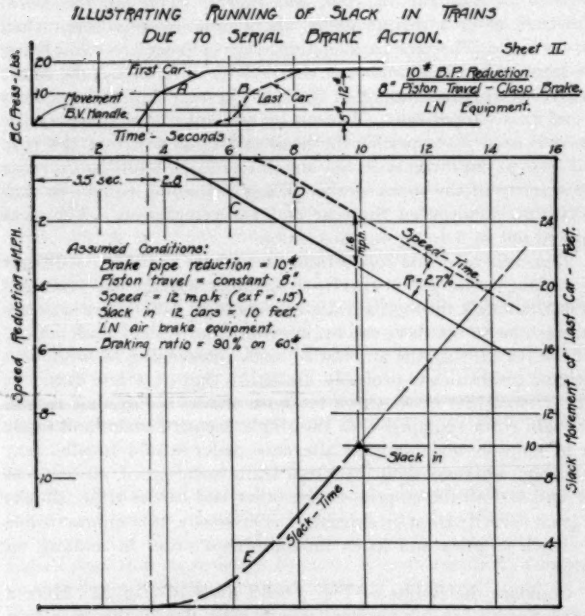
Remember, in this connection, that where variable conditions of braking ratio, piston travel, or cylinder leakage are scattered indiscriminately through a train, causing local differences in retardation to be set up, there can be, in general, no violent slack action, for the reason that the amount of slack intervening between two extreme conditions is probably limited to that of a few cars. It takes *cumulative slack action* to cause shocks. For that reason a freight train equipped with the single capacity brake and made up of empties and loads in alternate order would handle very smoothly, whereas, with the usual train make-up of all loads at one end and all the empties at the other end of the train, shocks of great severity must be expected. Obviously, it is impracticable to switch empties and loads into alternate order in making up trains.

Compare the results of Fig. 3 with those of Fig. 4. Here a retardation of but 2.7 per cent. is effective, due in this case to a lower brake cylinder pressure, and the velocity difference between head end and rear, for the same serial time of 2.8 seconds and the same total amount of slack of 10 feet, is proportionately reduced to 1.6 miles per hour; that is, *the less the retardation used until the slack closes in, the less severe will be the shock,* the amount of slack and serial time remaining the same. As before noted, this lessened retardation rate may be due to reduced cylinder pressures,

reduced braking ratio, or reduced coefficient of brake shoe friction due to higher train speeds; and the reduced cylinder pressure may be due to a lengthened piston travel or to a light brake pipe reduction.

This explains why it is so necessary to make light brake pipe

FIG. 4.



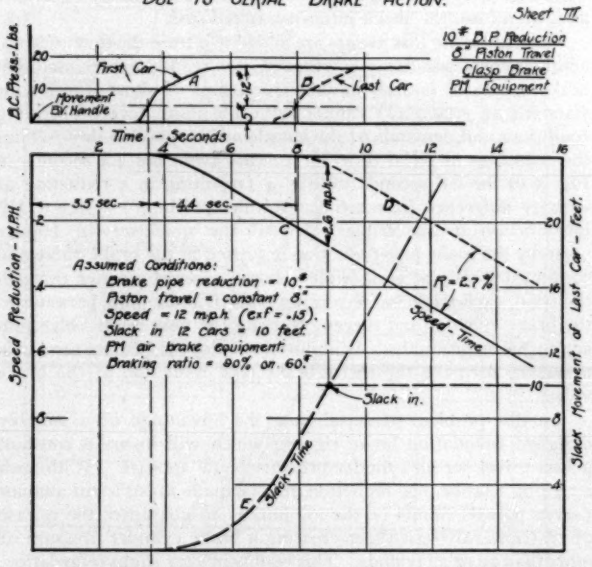
Compare with Fig. 3. With a certain time of serial action, the lower the rate of retardation set up the less will be the velocity difference between head end and rear when the slack closes in. This shows why brake applications on long trains must be started with a light brake pipe reduction.

reductions in applying the brakes on long trains at low speeds and why it is so necessary to have piston travel not too short, but of the proper length. This in turn explains the necessity of having foundation brake rigging which will not permit a material increase in piston travel as the cylinder pressure is increased, because the

slack adjuster, in making the travel proper at 8 inches for full cylinder pressure, throws back the piston position for the lighter pressures; that is, the cylinder pressures for light brake pipe reductions are far in excess of what they should be, due to the shortened piston travel. This variation or increase in piston travel between

FIG. 5.

ILLUSTRATING RUNNING OF SLACK IN TRAINS DUE TO SERIAL BRAKE ACTION.



Compare with Fig. 4. Increased time of serial action due to type of air-brake equipment or to number of cars in the train means increased velocity difference between the head and rear ends of the train and shocks of corresponding intensity.

that for the five or ten pounds pressure necessary to bring the shoes just against the wheels, and the full service pressure of 50 or 60 pounds, is known as "false" piston travel. In the discussion on "Foundation Brake Rigging" this will be described to better advantage.

Fig. 5, when compared with Fig. 4, illustrates the effect of the

time of serial brake action on shocks in a train. This time is here 4.4 seconds, as compared with 2.8 seconds on Fig. 4. The retardation is the same in each case (2.7 per cent.), and also the slack (10 feet), but the velocity difference is 2.6 miles per hour instead of 1.6; that is, *the severity of the running of slack is directly proportional to the time of serial brake action.* It is easily seen that in bringing the curves *C* and *D* of Fig. 4 closer together, as compared with Fig. 5, by reducing the time element, the velocity difference and, therefore, the shock intensity, is reduced.

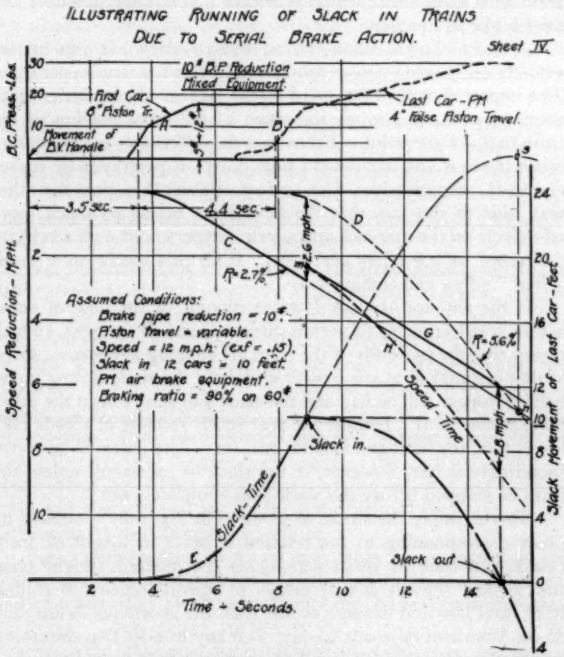
Remembering that as cars are added to a train the time of serial action is correspondingly lengthened, it is readily appreciated that brake apparatus entirely suitable for trains of short length (the standard of yesterday) cannot serve the more severe operating conditions and demands of the lengthened train of to-day. Thus the reduction in serial time for 12 cars from the 4.4 seconds in Fig. 5 to the 2.8 seconds of Fig. 4 (resulting in a reduction of velocity difference from 2.6 to 1.6 miles per hour) is due to the introduction in the triple valve of the quick-service feature whereby the brake pipe reduction is started at the brake valve and continued locally at each triple valve in a serial manner through the train, each triple valve venting a bit of brake pipe pressure to the brake cylinder and thereby starting the next triple valve into action more promptly. Without the quick-service feature it is necessary to make the entire brake pipe reduction at the brake valve.

In this problem of serial time the advantage of a suitably designed foundation brake rigging which will insure a constant piston travel for all cylinder pressures now appears. With such a rigging a brake pipe reduction may be made in sufficient amount (seven pounds should be the minimum) to guarantee the release of all triple valves, without creating a brake cylinder pressure of more than 10 or 12 pounds. This results in very slight retardation, and the slack closes in with small velocity differences and, therefore, negligible shocks. The slack may not be all in by the time the second brake pipe reduction is started, but the triple valves are now in service lap position and the drop in brake pipe pressure required to move the triple pistons alone, instead of the pistons and slide valves together as when the first reduction was made, is comparatively slight. That means that the time of serial action is greatly reduced; and likewise the velocity differences by the

time that the small amount of slack remaining closes in. The final result is an absence of any noticeable shocks.

Fig. 6 represents a combination of mixed conditions in the train. A comparatively small retardation is set up on the head end

FIG. 6.



Lack of uniformity in retardation due to differences in cylinder pressure or in braking ratio may cause a surging of slack, first in one direction and then in the other. This shows why the Empty and Load Brake makes more certain the smooth handling of long trains. Uniform piston travel and tight cylinder leathers contribute to the elimination of surges or slack action.

(2.7 per cent. here), due in this case to proper piston travel and a correspondingly light cylinder pressure. Due to "false" piston travel, and consequent high cylinder pressure, the retardation on the rear end is great (a final value of 5.6 per cent.). This same

condition can, and does, occur when the cylinder pressures are uniform but the braking ratio on the head end is low and that on the rear end is high, as in the case of load carrying mail, baggage, express, or refrigerator cars, and double-heading locomotives on the head end of passenger trains, or as in the case of a freight train with loads ahead, empties behind, and lacking an empty and load brake equipment.

As here shown, when the 10 feet of slack has run in, the velocity difference between head end and rear is 2.6 miles per hour. The impact decreases the speed of the last car almost instantly to some point *m*, and raises the speed of the front portion of the train to this same point. From here the differences in retardation cause the first and last cars to slow down, as portrayed by curves *G* and *H*, respectively. The 10 feet of slack then runs the other way, due to the fact that the brakes are acting so much more effectively on the rear end, and a jerk is experienced with a velocity difference of 2.8 miles per hour. With this condition a shock is had "going and coming."

If the amount of slack is great enough, or the time of serial action small enough, to permit curves *C* and *D* to cross (which means that the two ends of the train are running at the *same* speed at that instant) as at some point *n* without the slack closing in, no buffing impact will be had and the slack will start to run the other way, as shown at *s*, because the rear end is running at speeds ever lower than the head end as time goes on. The jerk will be correspondingly worse, however, if the slack be increased, unless the train be stopped before the slack runs completely out.

Now multiply the situation pictured in Fig. 6 by a number of times corresponding to the relation it bears in length of train (slack and time of serial action) to the modern freight train and wonder why it is that delays in transit, repairs to rolling stock, and loss and damage claims total the enormous figure they do on American railroads to-day. Is it any wonder that the empty and load brake was developed to overcome that exceedingly bad condition of having loaded cars on the head end braking at 15 per cent. and the empties at the rear with a braking ratio of 60 per cent.? If the positions of the empties and the loads be reversed there would be no jerk, but there would need to be none, for the run-in or buff would buckle the train practically every time the brakes were applied, due to both the mass and the low braking

ratio of the loads on the rear end. The rôle and purpose of the empty and load brake in making uniform the braking ratio, and likewise the retardation on the empty and loaded cars, can, therefore, be well appreciated by the resulting decrease in rough handling of trains and damage to lading and equipment.

You will appreciate, I am sure, that my endeavor is to point out what are the causes of unsatisfactory results in train control: results such as improper or neglected adjustments, deficient maintenance, manner in which trains are made up, in some cases inadequate train control, and improper manipulation on the part of the operator. What I desire to impress upon you most forcefully is that these undesired results are not inherent in the operation of trains, as unfortunately seems to be the impression of some people—for adequate train control apparatus is obtainable, and realization of its full value requires only a comprehension and application of the principles underlying its service.

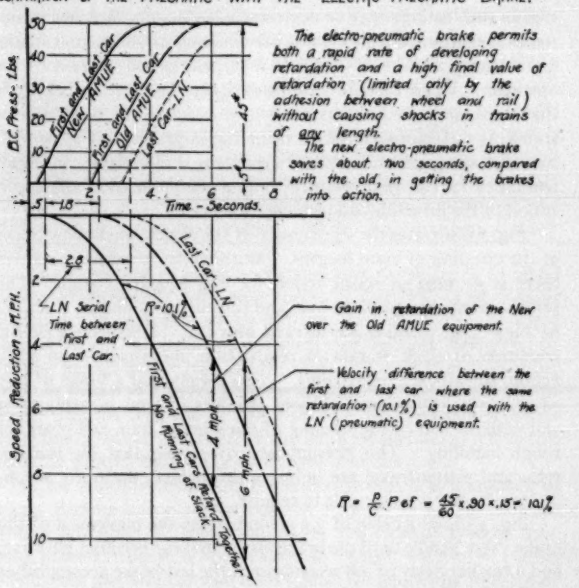
Fig. 7 illustrates the significance of the electro-pneumatic brake in the question of train lengths. With electro-pneumatic control there is *no* time of serial action for *any* length of train. The brakes on all cars go on as one, and the curves *A* and *B*, *C* and *D* of Figs. 3, 4, 5 and 6 are merged into one. Irrespective of the condition of slack or rate of retardation, there can be no slack action, for all cars retard alike. This means that a brake of *any effectiveness* can be used without any loss of time in applying it and without fear of the running of slack in the train and resultant rough handling. This presupposes, of course, that the braking ratio and piston travel are uniform throughout the train, a condition which it is reasonable to require.

Fig. 3 shows a delay of 3.5 seconds from the movement of the brake valve handle until the brake on the first car becomes effective, and a further delay of 2.8 seconds until the last brake accomplishes anything. These delays are due to the time required for air to flow from the brake pipe, for triple valve parts to move, and for air to flow from the auxiliary reservoir to the brake cylinder. Fig. 7 shows for the old electro-pneumatic equipment (AMUE) a delay of only 2.3 seconds from the operation of the brake valve to the application of all the brakes on the train. This application is effected by simultaneously reducing with an electromagnet the brake pipe pressure locally on every car. The delay, or dead time,

is due to the movement of the triple valve parts in sequence, and the flow of air from the auxiliary to the cylinders. The newly evolved electro-pneumatic brake, however, cuts down this dead time

FIG. 7.

CHARACTERISTICS OF THE OLD AND NEW ELECTRIO-PNEUMATIC BRAKE: COMPARISON OF THE PNEUMATIC WITH THE ELECTRO-PNEUMATIC BRAKE.


B.C. Press - Lbs.
50
40
30
20
10
First and Last Car New AMUE
First and Last Car Old AMUE
Last Car - LN
5"
5"
1.5
2
4
6
8
Time - Seconds.
Speed Reduction - M.P.H.
2.8
2
4
6
8
10
LN Serial Time between First and Last Car.
R=10.1%
Last Car - LN
First and Last Cars Retard Together
No Running of Slack.
Velocity P
Velocity Q
The electro-pneumatic brake permits both a rapid rate of developing retardation and a high final value of retardation (limited only by the adhesion between wheel and rail) without causing shocks in trains of any length.
The new electro-pneumatic brake saves about two seconds, compared with the old, in getting the brakes into action.
Gain in retardation of the New over the Old AMUE equipment.
Velocity difference between the first and last car where the same retardation (10.1%) is used with the LN (pneumatic) equipment.
R = P/C P ef = 45/60 x .90 x .15 = 10.1%

Cutting down the time of serial action to zero by employing the electro-pneumatic brake entirely removes slack action for any rate of retardation and for any amount of slack. It is necessary, however, to have the braking ratio and piston travel uniform throughout the train.

The best brake—the entire train considered—is the one which, in affording the best rate of retardation, creates the least velocity differences between the various vehicles in a train.

to half a second by eliminating the necessity for the movement of the pneumatic parts of the triple valve and by cutting down the time for the flow of air from the auxiliary reservoir to the brake cylinder. The advantage of this saving may be grasped by noting

that at the end of six seconds from the movement of the brake valve the train equipped with the new brake is running a little more than eight miles per hour slower than the initial speed ,and four miles per hour slower than the train with the old electro-pneumatic brake; also, this is seven miles per hour slower than the first car of the train equipped with the straight pneumatic brake (see Fig. 4) where the maximum retardation is used consistent with tolerable shock conditions. Bear in mind that with the electro-pneumatic brake it is not a question of *tolerable* shock, but one of *no shock whatever*.

Just to convey some idea of what it would mean to use with straight pneumatic equipment a rate of retardation equal to that (10.1 per cent.) shown for the electro-pneumatic brake on Fig. 7, dotted curves have been added to represent the performance of an LN pneumatic equipment on the last car of the train of Fig. 3. The retardation curve for this is separated from the one used to represent the first car (new AMUE) by a time of 2.8 seconds, the serial time shown in Fig. 3. The velocity difference between head end and rear is seen to be *six miles per hour*. Does not this make clear the relation between train control devices and the ability to run longer trains more smoothly and with less loss of time?

From the foregoing it will be clear that, notwithstanding the greatly increased train weights and lengths of recent years, brake development has kept at least an equal pace with the requirements of adequate train control. The capacity of modern brake apparatus is far from exhaustion, the only consideration being that proper engineering be employed in the choice of brake equipments for the conditions to be met and due care be exercised in its installation, with particular reference to the maintenance of proper volume proportions. As to volume relationships, however, more will be said under the division "Foundation Brake Gear."

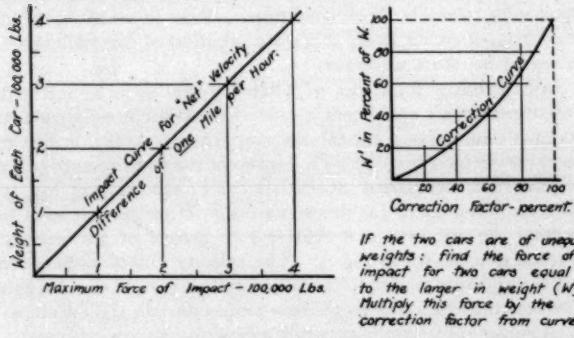
IMPACT.

So far impacts have been spoken of in terms of velocity difference only. Fig. 8 has been prepared to show what the actual force of impact may be. *This curve shows that for each net velocity difference of one mile per hour the maximum blow due to impact is equal to the weight of one of the colliding vehicles.* If the net velocity difference be twice this, or two miles per hour, the blow

will have twice the intensity; if three miles per hour, three times the blow, etc. By "net" velocity difference is meant the actual velocity difference less one mile per hour, which is a rough-and-ready allowance to give for the capacity of a draft gear. This, of

FIG. 8.

MAXIMUM FORCE OF IMPACT BETWEEN TWO CARS.


Weight of Each Car - 100,000 Lbs.
Maximum Force of Impact - 100,000 Lbs.
Impact Curve for "Net" Velocity Difference of One Mile per Hour.
W' in Percent of W.
Correction Curve
Correction Factor - percent.

If the two cars are of unequal weights: Find the force of impact for two cars equal to the larger in weight (W). Multiply this force by the correction factor from curve.

With Inelastic Impact as Basis (Coefficient of restitution = 0):

$$F_a t = \frac{M M'}{M + M'} (v - v')$$

where M, v = Mass $\left(\frac{W}{g}\right)$ and velocity (ft. per sec.) of one car.
M', v' = " $\left(\frac{W'}{g}\right)$ " " " " " second -
F_m = Maximum impact force.
F_a = Average impact force during period of impact.
= .76 F_m
t = period of impact = .03 seconds.
$(v - v')$ represents a "net" velocity difference (actual minus one) of one mile per hour.

The maximum force of impact is proportional to the net velocity difference. If the latter is 2 m.p.h. instead of 1 m.p.h. the impact forces will be double those given above, etc.

For every mile per hour "net" velocity difference (actual difference less one) the force of the impact due to one car colliding with another is approximately equal to the car weight.

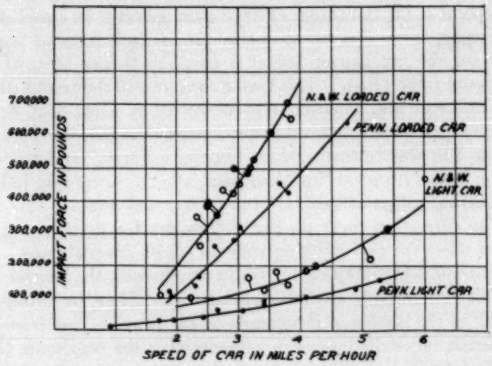
course, will vary with the weight of vehicle and the characteristics of the draft gear. A net time of 0.03 second has been assumed as the total period of impact. By "net" time is meant the time of impact, neglecting the part played by the draft gear, which has been sufficiently allowed for in determining the net velocity differ-

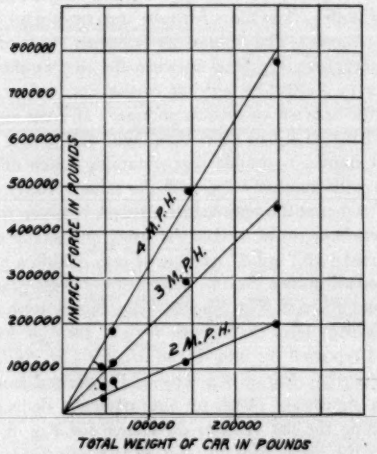
ence. In other words, the " net " time for impact is started from some point in the last stages of draft gear action. In establishing this impact curve it is assumed that the *average* force of impact (F_a) for the net impact period is equal to 76 per cent. of the maximum force (F_m). This factor conforms to the results of the very elaborate and scientific tests conducted by Lieut.-Col. B. W. Dunn on "A Photographic Impact Testing Machine for Measuring the Varying Intensity of an Impulsive Force," and reported by him in this JOURNAL for November, 1897. According to him, the limiting values of this factor are 0.637 and unity.

The correction curve on Fig. 8 provides for determining the impact when the two colliding vehicles are of unequal mass. To use it, assume that both cars agree in weight with the heavier and find this maximum blow in the regular way. Then, by noting the weight of the lighter in percentage of the heavier, find from the correction curve the impact in percentage of the maximum blow first found. For instance, suppose the net velocity difference between an 80,000-pound car and one weighing 100,000 pounds to be one mile per hour. The blow for two 100,000-pound cars would be 100,000 pounds. The lighter car is 80 per cent. of the other in weight; therefore, the blow between the two as shown by the correction curve is about 88 per cent. of that for two cars weighing as much as the heavier, or 88,000 pounds. If a car collides with a " solid " string of ten or more cars equal to the first in weight, the force of impact is double that obtaining when one of these cars collides with another only, with the same velocity difference. By " solid " is meant the removal of all slack between the cars due to the couplers being solid, so that the bunch acts as one continuous vehicle. In case two " solid " groups of cars collide a proportionately modified allowance must be made for the draft gear capacity.

The values given in Fig. 8 agree quite closely with the results of careful impact tests made with freight cars by Prof. L. E. Endsley and reported by him in the *Master Car Builders' Proceedings* for 1915. Fig. 9 is a copy of the plotted results of his tests. As a significant check on the arbitrary deduction made for determining the net velocity difference for Fig. 8, note that the curves in the upper chart of Fig. 9, if continued, would pass through the base line at approximately one mile per hour. Reading from the lower chart, it is seen that for a total velocity differ-

FIG. 9.





Force of Impact Between Freight Cars.

Results of impact tests made by Prof. L. E. Endsley.

ence of three miles per hour (net difference of two according to the above basis) a 200,000-pound car gives 375,000 pounds—almost 400,000—as the force of impact. According to Fig. 8, the impact would be 400,000 pounds.

SLID FLAT WHEELS.

The relation between impacts, due to slack action in trains, and slid flat wheels is not as apparent as it should be if due appreciation is to be given to the causes for the acute and chronic suffering of our railroads from this form of damage to equipment. Wheels slide because the fulcrum (or pivot about which the wheel moves with relation to the rail) at the point of rail contact fails; that is, the demand on the rail in the way of thrust exceeds the adhesion or static friction between the wheel and the rail. A buff or jerk in the direction of motion of the train increases the car velocity and the rotative speed of the wheels. A certain thrust on the wheels is required of the rail to increase their angular velocity. If the brakes are applied this rail thrust due to impact is augmented by the thrust set up by brake shoe friction. The sum of the two thrusts must not exceed the adhesion if the wheels are not to slide. If this total does exceed the adhesion, the car is said to be "knocked off its feet." An impact opposite to the direction of train motion neutralizes the rail thrust due to braking, but may carry the thrust beyond in the other direction up to the limiting value of adhesion, with like result, only the impact required to do this must be correspondingly greater than the first. In other words, the total rail thrust is equal to the algebraic sum of the thrust set up by the impact and that caused by braking.

The impact "knocking the car off its feet" lasts a very short time only, and the rail thrust brought into play by this impact lasts only as long. But brake shoe friction in this very short interval of time has jumped up in value, becoming static in nature where it was kinetic before, and the wheel-rail friction has dropped in value, becoming kinetic where it was static or rolling before, and the wheels may continue to slide. The continued sliding of the wheels depends upon these changes in value of shoe-wheel and wheel-rail friction being sufficient to make the former greater than the latter. This will, in turn, depend, of course, on the relation of the shoe pressure to the weight on the wheel and the condition of the surfaces of the shoe and rail. Where sliding does persist—

and it is only too often—it may be said that the impact has "knocked the car off its feet" and brake shoe friction holds it "off its feet."

As a numerical illustration: A freight car weighing 50,000 pounds has an adhesion of 3125 pounds per pair of wheels if the adhesion factor is 25 per cent. A cylinder pressure of 29 pounds gives 690 pounds brake shoe friction per pair of wheels for a braking ratio of 60 per cent., based on 50 pounds cylinder pressure and an efficiency factor of 15 per cent. An impact of 200,000 pounds will bring the total rail thrust up to the above adhesion limitation. A greater braking force, a greater impact (which is not unusual in service), or a reduced adhesion will result in the car being "knocked off its feet" by the impact. If the brake shoe friction at this instant exceeds the wheel-rail friction, the car will be kept "off its feet." This will be true if the rail friction drops to 1250 pounds (10 per cent.) and the shoe friction doubles to 1380 pounds (efficiency factor rising to 30 per cent.), due to the respective changes from static to kinetic friction, and *vice versa*. Under the same conditions an impact in the opposite direction must exceed 300,000 pounds to knock the car off its feet. This impact computation is based upon two 700-pound wheels on a 500-pound axle, having a combined moment of inertia of 143.

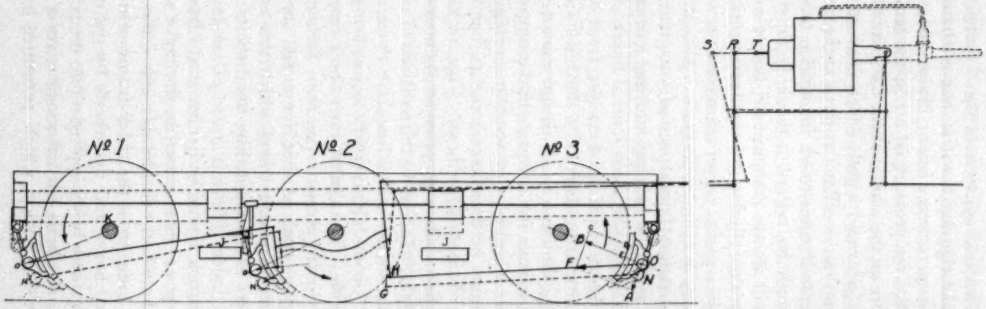
From the foregoing it can be seen that shocks in long trains must be subdued or eliminated if slid flat wheels and the host of other troubles are not to be had.

FOUNDATION BRAKE RIGGING.

No discussion on the matter of train control can in any sense be complete without some reference being made to that part of a brake installation known as the foundation brake rigging. A volume might be written on the subject, but brief mention only will be made here.

As a chain is no stronger than its weakest link, and measures to increase the efficiency of that chain should patently start with that weakest link, so it is also true that the advantages of improved types of air-controlling devices can be realized only in minor degree unless improvements be made in that link; namely, the foundation brake gear, which to-day is the link weakest in efficiency in the whole air brake system. The term "link" takes on

FIG. 10.



Low-hung brake shoes result in the brake hangers pulling the truck frame down about the journal boxes. This permits the shoes to slip still further down on the wheel treads, causing increased or "false" piston travel. The forcing of journals from under their brasses by unbalanced shoe pressures and lack of rigidity in truck construction are also sources of false piston travel.

If for full brake applications (heavy cylinder pressures) the piston travel be correct, which the automatic slack adjuster serves to make it, it will be much *too short* when the light brake pipe reductions are made. To dispense with the slack adjuster would be to risk striking the non-pressure cylinder head with the brake piston and losing the brake to that extent.

Piston travel too short means that the cylinder pressures for these light reductions are much too high; that is, light cylinder pressures are unattainable.

The final result is the *loss of brake flexibility;* the brake must be either "off" entirely or "on" heavier than desired, with rough train handling as the inevitable consequence.

a double meaning when one appreciates the "connecting" rôle of the foundation brake rigging, for it is that mechanical system of levers, rods, pins, hangers, brake beams, brake shoes, etc., which transmits and multiplies the pressure of air in the brake cylinder into brake shoe pressure on the wheels of the car. It is the connection between brake cylinder and wheels which converts fluid pressure at the former point into mechanical force at the latter.

The first and essential requisite of foundation brake rigging is that it be designed with due regard to the strength, rigidity, and arrangement which will always maintain the proper volume proportions between the brake cylinder and auxiliary reservoir; that is to say, it must provide a piston travel constant as nearly as possible under all variations in cylinder pressure. Also, it should not apply to the wheels' unbalanced lateral pressures so great as to force the journal out from under its bearing, causing journal troubles, and to cause excessive binding between journal boxes and pedestal jaws, thereby permitting a shifting of weight from one pair of wheels to another, due to irregularities in the track surface, and causing wheel sliding. Suitable truck design cannot be dissociated from these requirements for adequate brake rigging.

The single-shoe-per-wheel type of foundation rigging in such prevalent use meets none of these requirements, but is a sinner of the first order in its disregard for them. Figs. 10 and 11 illustrate the lack of proper volume proportion maintained by this single-shoe type of rigging. In Fig. 10 the positions of rods, levers, truck frame, and shoes, shown in full lines, are those for the cylinder pressure (about 5 pounds) necessary to just bring the brake shoes against the wheels. The dotted lines show corresponding positions when the cylinder pressure has been built up to some value appreciably higher, such as that for a full service application. The difference in piston travel which this variation in cylinder pressure makes is represented by the distance *RS* on the center line of the cylinder. *This is false piston travel.* The pulling down of the truck frame and other parts from the full line to the dotted line positions is caused by the brake shoes being hung at a point on the wheel considerably below the horizontal center line and being hung from the truck frame, which is separated from the journal boxes and the wheels by the usual truck springs. The braking force being applied along the pull rod *OH* (note the No. 3 pair of wheels for lettering) gives a tangential component *OA* at the brake shoe, which, permitted by the just-

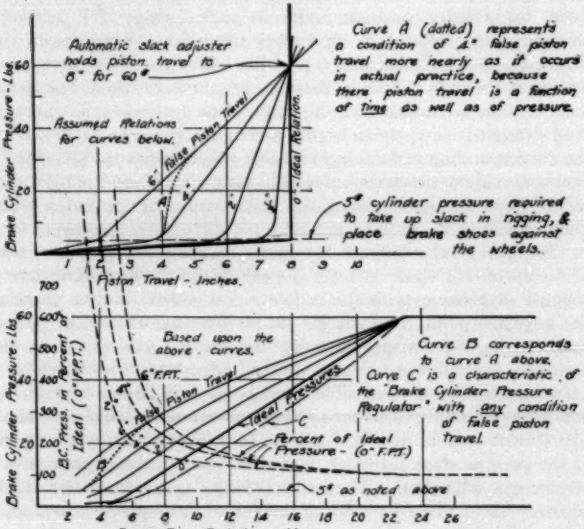
mentioned spring suspension, pulls the shoe down into the dotted position, and this cumulative effect on each wheel results in the false piston travel *RS*. The operation of the automatic slack adjuster returns point *S* and, of course, point *R* towards point *T* until distance *TS* equals the setting of the slack adjuster. This reduces distance *RT* and, therefore, the brake shoe clearance for release position until in many cases *RT* actually becomes zero. Point *T* represents the release position of the piston and point *R* that piston position where the shoes first come against the wheels. That is, there is very much reduced shoe clearance or none whatever with the single-shoe type of brake rigging. And dragging shoes mean highly increased train resistances, with the corresponding reduction in motive power capacity, increase in fuel and water (or electric power) consumption, and shocks due to the necessity for "taking the slack" in order to get a train under way.

The point very difficult for many to grasp, when this action of the automatic slack adjuster is explained, and they immediately suggest dispensing with the adjuster altogether, is that without the adjuster point *S* might go out so far that the brake piston would strike the non-pressure cylinder head. And this it would do unless careful and repeated manual adjustments were made—adjustments almost impossible to accomplish in the comparatively minor degree required under present conditions. Moreover, such adjustments would merely duplicate in a laborious way the work of the present slack adjuster, and this remedy would provide no betterment whatever. The only "fault" the automatic slack adjuster has is that of revealing the evil of false piston travel and the necessity for striking at the fundamental cause in order to effect a cure. Also, in this same connection, it is well to mention that the slack adjuster should take up about one thirty-second of an inch only for each operation instead of the full distance the piston travels beyond the adjuster setting. Otherwise, where the full overtravel is taken up with one adjuster operation, an unusually high cylinder pressure, such as obtained in emergency, would cause the shoes to grip the wheels with the air exhausted from the cylinder, to such an extent that the car could not be moved at all.

The distance *RT* represents the piston travel for light brake pipe reductions, and, as before pointed out, short piston travel

means correspondingly high cylinder pressures and, therefore, severe shocks in long trains, due to serial brake action. Fig. 11 shows what this false piston travel means in the way of giving high cylinder pressures for a light brake pipe reduction at just

FIG. 11.


Automatic slack adjuster holds piston travel to 8" for 60#
Curve A (dotted) represents a condition of 4" false piston travel more nearly as it occurs in actual practice, because there piston travel is a function of time as well as of pressure.
Assumed Relations for curves below.
6" False Piston Travel
0" - Ideal Relation.
5# cylinder pressure required to take up slack in rigging, & place brake shoes against the wheels.
Brake Cylinder Pressure - Lbs.
Piston Travel - Inches.
Based upon the above curves.
Curve B corresponds to curve A above.
Curve C is a characteristic of the "Brake Cylinder Pressure Regulator" with any condition of false piston travel.
6" F.P.T.
4" False Piston Travel
Ideal Pressures
Percent of Ideal Pressure - (0" F.P.T.)
5# as noted above
Brake Pipe Reduction - Lbs.

EFFECT OF FALSE PISTON TRAVEL ON BRAKE CYLINDER PRESSURES FOR VARIOUS BRAKE PIPE REDUCTIONS.

"False" piston travel makes it impossible to obtain light cylinder pressures with the minimum brake pipe reduction required to properly operate the triple valves. This is true if the piston travel be correct for full pressures. Heavy cylinder pressures can always be obtained by increasing the brake pipe reduction. But to have *flexibility* requires that it be possible to apply the brake *lightly* when so desired.

the time when they are not wanted. When high pressures are desired heavier brake pipe reductions can readily be made, *but if flexibility is to be had it is indispensable that the brake installation permit obtaining light cylinder pressures as well as heavy ones.*

(*To be continued*)

THE EFFECTS OF EXPOSURE ON TAR PRODUCTS.*

BY

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IT has been shown on several occasions that changes occur in bituminous materials on exposure to the action of air and sun. Such changes are not due merely to the volatilization of lighter oils, as shown in a previous paper [1] upon this subject, but also to chemical changes in certain constituents of the bitumen, such as molecular rearrangements, inter-reactions, and oxidation. Changes of such a nature were demonstrated in the case of native asphalt and petroleum products by abnormal increases in the percentage of bitumen insoluble in paraffin naphtha, and in the case of tars by abnormal increases in the percentage of free carbon.

The present study was instituted for the purpose of extending the work through a greater range of tar products and to determine what relation, if any, existed between the changes brought about by exposure and those produced by laboratory distillations.

Seven samples were chosen, including two refined coal-tars, one refined water-gas tar, one refined mixed tar, two tar-asphalt mixtures, and one crude coke-oven tar. The results of the usual examination made according to methods published in Bulletin 38 [2] of the Office of Public Roads, United States Department of Agriculture, are given in Table No. 1. In addition, a dimethyl-sulphate test as described in United States Department of Agri-

* Communicated by Logan W. Page, Director, Office of Public Roads and Rural Engineering, Washington, D.C.

[1] *Jour. Ind and Eng. Chem.* (1913), vol. 5, No. 1. A paper presented at the Eighth International Congress of Applied Chemistry, New York, September, 1912.

[2] "Methods for the Examination of Bituminous Road Materials."

TABLE I.

Analyses of Samples Used in Exposure Tests.

Material	Refined coal-tar		Refined mixed tar		Crude coke-oven tar		Refined coal-tar		Tar-asphalt mixture		Water-gas tar preparation		Refined water-gas tar	
Sample number	3896		4797		5123		5627		5992		6672		X	
Specific gravity 25°/25° C.	1.215		1.244		1.206		1.256		1.177		1.126		1.184	
Float test at 32° C.	1′ 5″		.....		.....		.....		1′ 30″		.....		.....	
Float test at 50° C.	.....		4′ 29″		.....		2′ 16″		42″		.....		2′ 21″	
Viscosity Engler, 50 c.c. at 50° C.	.....		.....		.....		.....		.....		29.8		.....	
Bitumen soluble in CS_2	.....		82.79		91.16		70.29		85.35		97.40		99.23	
Free carbon	19.36		17.13		8.77		29.65		14.57		2.47		0.72	
Inorganic matter soluble	.....		0.08		0.07		0.06		0.08		0.13		0.05	
	.....		100.00		100.00		100.00		100.00		100.00		100.00	
Distillation	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight
Water	0.0	0.0	0.0	0.0	1.0	0.8	Not made		Trace	Trace	0.0	0.0	Not made	
First light oils (to 110° C.)	0.2	0.2	0.0	0.0	0.4	0.3			0.3	0.2	0.6	0.5		
Second light oils (110°–170° C.)	3.2	2.5	0.4	0.3	2.0	1.7			0.6	0.4	1.9	1.6		
Heavy oils (170°–270° C.)	29.6	25.1	23.2	18.8	14.0	12.3			18.2	15.6	21.4	18.8		
Heavy oils (270°–315° C.)	.....	.....	.....	.....	7.9	6.9			9.7	8.5	14.5	13.1		
Pitch residue	*67.0	*72.0	*76.4	*80.4	74.7	77.6			71.2	74.6	61.6	65.9		
Total	100.0	99.8	100.0	99.5	100.0	99.6			100.0	99.3	100.0	99.9		

Dimethyl Sulphate Test:

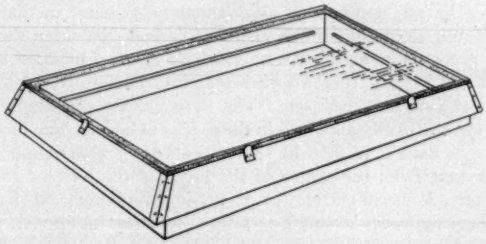
Per cent. insoluble (270°–315° C. fraction)	1.25	7.5
Per cent. insoluble (315°–350° C. fraction)	12.5	10.0
Per cent. insoluble (350°–375° C. fraction)	28.5	7.5

* Distillation made by old method (to 270° C.).

culture Bulletin No. 314 [3] was performed on distillates from the two tar-asphalt preparations.

Briefly stated, the method of procedure was as follows: Samples of each material were exposed to the action of sun and air for three months, which the previous investigation seemed to indicate was sufficient to bring about the maximum changes desired. Examinations were made at the end of each succeeding month to determine the change in weight and extent of hardening. In order to compare the effect of exposure with straight distillation, distillations in an Engler flask were made on each sample to produce a residue corresponding, in percentage by weight of the amount taken, to the residue produced on exposure,

FIG. 1.



Box used for exposure tests.

and the consistency of the residues thus produced was determined. Changes in the samples due to volatilization or other causes were noted by estimation of the percentage of material insoluble in carbon disulphide in the various residuums.

The exposures were made in a box of the same type used in previous work, shown in Fig. 1. It was made of ¾-inch wood and had interior dimensions of 25 by 14½ by 2 inches. This was covered with a plate of ¼-inch plate glass resting on a strip of thick felt fastened to the sides of the box so as to make a tight joint and exclude all dust. Slots ¼ inch wide were cut through each side of the box, and to prevent the entrance of rain these were protected by a thin board extending from the rim at

[3] Revision of Bulletin 38.

an angle of about 45 degrees. Cotton batting was packed under this board against the slots to exclude dust from the outside air.

To approximate the constant circulation of air over bituminous materials exposed to actual service conditions, a current of air taken from a pressure pump and passed through a water wash-bottle to remove dust was introduced through a glass tube which passed through one of the slots and terminated at the centre of the box. The tube is shown in Plate I, which represents one-half of the box. This constant current of dust-free air tended also to keep dust from entering the box, and at the end of three months the clean, glossy surface of the harder samples demonstrated that practically no error had been introduced by contamination with dust.

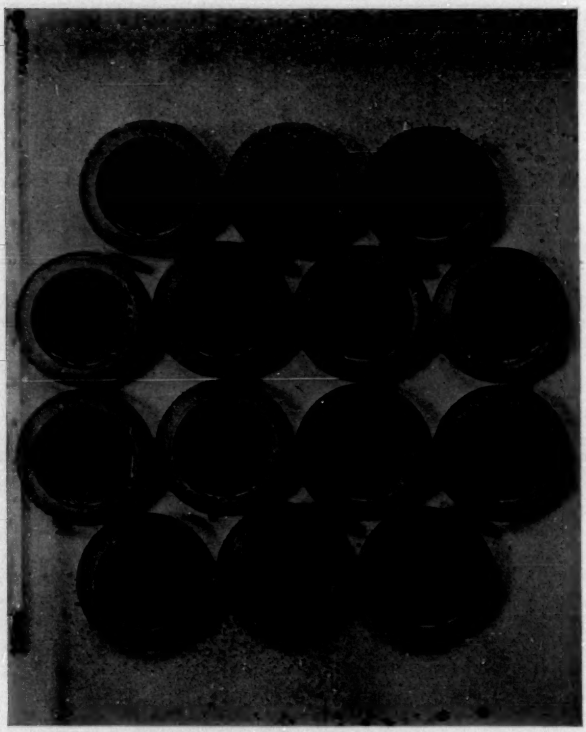
The samples to be exposed were placed in Syracuse watch-glasses having depressions approximately 47 mm. in diameter and 8 mm. deep. Four specimens of each of the seven samples were prepared by accurately weighing 12 gms. of bitumen into a tared watch-glass, thus insuring practically a uniform depth of material for each specimen. The twenty-eight specimens were then symmetrically arranged in the exposure box in four rows, as shown in Plate I, so that the four of each particular sample were equidistant from the centre of the box and the inlet of the air current. A thermometer was placed in the middle and the box set lengthwise on a shelf outside a window having an open southern exposure. The box was exposed in the late afternoon of April 21.

The next morning at 9 o'clock it was noted that brilliant white flaky crystals of naphthalene had formed on the under side of the glass. The temperature recorded in the box at this time was 35° C., but this gradually increased, and the crystals began to melt to a colorless oil. From Plate I, which was photographed at this time, it may be seen that the sublimation is greatest over the specimen numbered 3, which is sample No. 5123, the crude coke-oven tar.

At the expiration of one month's time all the specimens were removed from the box and weighed to determine their loss in weight for each set for this time. Three sets were then replaced in the box for continued exposure in the same position they had previously occupied, while the fourth was subjected to tests to determine its consistency and percentage of free carbon. The

consistency was determined by float tests at 100° C., a temperature which it was felt would be sufficiently high to provide for a

PLATE I.

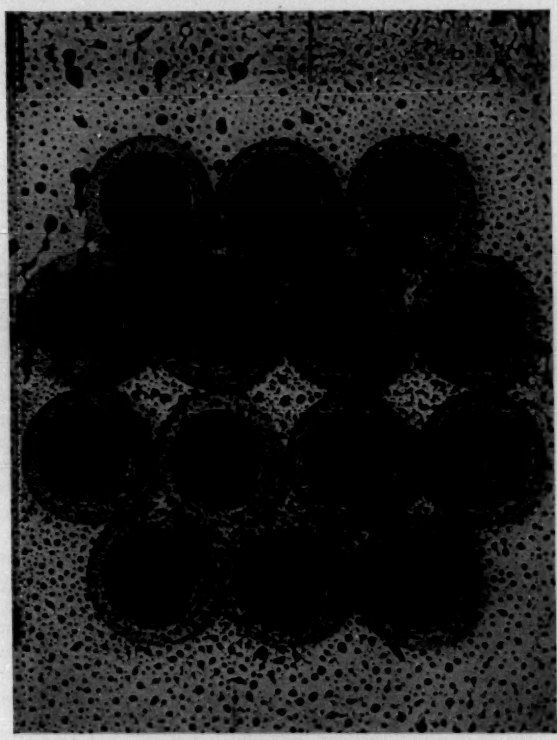


Appearance of exposure box after 24 hours.

satisfactory test on later samples, and also by penetration tests at 25° C., 100 gms., 5 seconds, when the material was sufficiently solid to permit it.

The above procedure was repeated at the expiration of the second and third months. At the end of each month an irregular

PLATE II.



Right half of exposure box, showing appearance of hardened, gum-like distillate on under surface of glass.

deposit of a red, gum-like substance, previously noted by Hubbard and Reeve,[4] was found on the under side of the glass cover.

[4] *Loc. cit.*

Plate II shows the appearance of this deposit at the end of the first month. Each time, before the cover was replaced, the gum, which is partially soluble in ethyl alcohol, but almost insoluble in carbon disulphide or benzol, was removed.

During the three months' exposure a current of air was passed through the box during the hours from 9 A.M. to 4:30 P.M.; the rate of flow was measured occasionally and averaged about 0.4 cubic feet per hour, a rate which would displace the atmosphere within the box about once per hour. During the first month readings were taken of the temperature inside the box at 9 A.M., 2 P.M., and 4:30 P.M., and it was found that the average temperatures were as follows: At 9 A.M., 27° C.; at 2 P.M., 57° C.; at 4:30 P.M., 37° C. On heavily clouded days the temperature varied but little during the day, but on days when the sun shone very brightly the temperature advanced rapidly from 9 to 2 o'clock, a maximum rise of 46° C. being recorded, from 25° to 71°. On such days the temperature at 2 o'clock varied from about 68° C. to 79° C. This is, of course, a higher temperature than would obtain in service conditions, and for purposes of study and comparison this work must be considered as possessing the character of an accelerated test.

Table II presents the values obtained by examination of the residues for the three months' exposure, together with corresponding values for the original samples for comparative purposes. In reviewing the table it may be seen that the average loss on a set of samples tested at the end of each period of exposure checks reasonably with the losses on the individual samples for the same period, indicating that the values obtained in testing the residues thus obtained are fairly comparable from month to month. All the samples began to lose weight on exposure, and the loss increased during the entire term of exposure, with the exception of the heavy refined coal-tar, No. 5627, where the residue from the two and three months' exposures is practically the same percentage of the original, and likewise has the same consistency.

Allowing for some experimental errors, it is evident that the organic matter insoluble in carbon disulphide increased gradually even in the case of sample No. 5627, which did not lose in weight appreciably after the second month. Throughout the present discussion this organic matter has been referred to as free

carbon, although it is not unlikely that it may be partially composed of alteration products of tar distillates similar to the gum-like-substance formed on the glass cover of the exposure box.

An error in some of the determinations of free carbon at the end of the first month is particularly noticeable, but unfortunately sufficient material was not available for repeating this work.

TABLE II.

Tests on Samples Subjected to Exposure.

	Sample number.....	3896	4797	5123	5627	5992	6672	X
Time of exposure		Refined coal-tar	Refined mixed tar	Crude coke-oven tar	Refined coal-tar	Tar-asphalt mixture	Water-gas tar preparation	Refined water-gas tar
Original	Float test.....	32° C 1′5″	50° C 4′29″	Fluid	50° C 2′16″	32° C 1′30″ 50° C 42″	Fluid	50° C 2′21″
	Free carbon.....	19.36	17.13	8.77	29.65	14.57	2.47	0.72
1 month	Per cent. loss, average of 4 specimens	10.17	2.27	17.68	7.26	10.76	19.32	3.25
	Per cent. loss, specimen tested.....	10.32	2.39	17.92	7.34	10.76	19.71	3.27
	Float test at 100° C.	24″	41.6″	30.3″	60″	34.1″	33.5″	28″
	Penetration, 25° C..	190	47	82	16	116	111	89
	Free carbon.....	25.21	22.46	14.94	33.18	19.46	8.31	3.06
2 months	Per cent loss, average of 3 specimens	12.08	3.23	19.81	7.87	12.11	22.37	5.87
	Per cent. loss, specimen tested.....	12.12	3.23	19.85	8.09	12.07	22.15	6.21
	Float test at 100° C.	33″	44.8″	37.5″	78.5″	34″	38″	43″
	Penetration, 25° C..	79	31	48	8	51	41	37
	Free carbon.....	23.56	20.06	15.15	32.51	18.73	9.27	4.69
3 months	Per cent. loss, average of 2 specimens	13.47	3.87	21.32	8.08	13.01	24.24	6.97
	Per cent .loss, specimen tested.....	13.39	3.77	21.21	7.85	12.84	24.18	6.67
	Float test at 100° C..	41″	55″	47″	78″	48″	59″	49″
	Penetration, 25° C..	50	28	18	11	47	19	20
	Free carbon.....	23.64	21.40	15.90	33.60	20.68	10.02	6.9

That the increase in percentage of free carbon is not due to loss by volatilization alone is evident from Table III, in which are given actual percentages of free carbon determined and the percentages calculated on a basis of the loss of volatile matter at each period. In every case the calculated percentage is shown to be less than the actual percentage, and it is of interest also to

note that the greatest difference occurs in samples wholly or partly of water-gas tar. The crude coke-oven tar shows a decided variation between calculated and actual percentages, while it may be noted that, in the case of the two refined coal-tars, the variation is comparatively small. From these data it seems logical to conclude that changes resulting in the formation of organic matter insoluble in carbon disulphide take place in tars exposed to the action of air and solar heat, but that this formation is less in the case of coal-tar than in the case of water-gas tar.

TABLE III.

Percentage Free Carbon, Actual and Calculated.

Sample number	Material	Original	Residue one month		Residue two months		Residue three months	
		Actual	Actual	Calculated	Actual	Calculated	Actual	Calculated
3896	Refined coal-tar.....	19.36	25.21	21.6	23.56	22.0	23.64	22.4
4797	Refined mixed tar.....	17.13	22.46	17.6	20.06	17.7	21.40	17.8
5123	Crude coke-oven tar...	8.77	14.94	10.7	15.15	10.9	15.90	11.1
5627	Refined coal-tar.....	29.65	33.18	32.0	32.51	32.3	33.60	32.2
5992	Tar-asphalt mixture...	14.57	19.46	16.3	18.73	16.6	20.68	16.7
6672	Water-gas tar preparation.....	2.47	8.31	3.08	9.27	3.18	10.02	3.26
X	Refined water-gas tar..	0.72	3.06	0.74	4.69	0.77	6.09	0.77

The second phase of this investigation was the comparison of residues obtained from the above exposure tests with those obtained from distillation of the original samples. To secure comparative data, distillations to 315° C. were made in 250-c.c. Engler flasks, according to the published method [5] now in use in the United States Office of Public Roads and Rural Engineering The temperatures of fractionation are those calculated to be the actual temperatures of the vapors, and are based on thermometer calibrations obtained on substances of known boiling-point; namely, water, naphthalene, and diphenylamine. Table IV gives the distillation data so obtained.

Distillations of the samples were then carried on to secure residues of the same percentage of the original material as was obtained by exposure for three months. The data secured in this work are given in Table V.

[5] U. S. Department of Agriculture Bulletin No. 314, "Methods for the Examination of Bituminous Road Materials," p. 21.

It is of interest to note that, while all samples were exposed to the same conditions of exposure, there is a difference of about 84° C. between the maximum and minimum temperatures to

TABLE IV.

Distillation of Samples to 315° C.

PERCENTAGES BY WEIGHT OF ORIGINAL SAMPLE.

Sample number.....	3896	4797	5123	5627	5992	6672	X
Material	Refined coal-tar	Refined mixed tar	Crude coke-oven tar	Refined coal-tar	Tar-asphalt mixture	Water-gas tar preparation	Refined water-gas tar
Per cent. water.....	Trace	Trace	0.50	Trace	0.0	0.0	0.0
Per cent. to 110° C...	0.0	0.0	0.17	0.23	0.28	0.0	0.0
Per cent. 110°–170° C.	0.15	0.0	0.00	0.00	0.00	0.26	0.0
Per cent. 170°–270° C.	13.65	0.51	14.42	8.09	14.45	11.08	0.67
Per cent. 270°–315° C.	5.74	4.11	2.75	5.23	6.36	11.60	3.20
Per cent. residue above 315° C.....	80.11	95.30	80.96	85.76	77.93	76.66	95.95
Total.....	99.65	99.92	98.80	99.31	99.02	99.60	99.82

TABLE V.

Distillation of Samples to Obtain Residues Corresponding to Residues from Three Months' Exposure.

PERCENTAGES BY WEIGHT OF ORIGINAL SAMPLE.

Sample number.....	3896	4797	5123	5627	5992	6672	X
Material	Refined coal-tar	Refined mixed tar	Crude coke-oven tar	Refined coal-tar	Tar-asphalt mixture	Water-gas tar preparation	Refined water-gas tar
Water.....	Trace	0.0	0.6	Trace	0.0	0.0	0.0
To 110° C.....	0.0	0.0	0.18	0.0	0.16	0.0	0.0
110°–170° C.....	0.09	0.44	0.00	0.19	0.0	0.09	0.0
170°–x° C.....	13.85	1.50	13.95	8.35	13.49	11.08	0.73
270°–xx° C.....	.....	2.11	3.27	.....	.....	11.49	3.85
315°–xxx° C.....	.....	.....	4.10	.....	.....	2.54	3.04
Residue above xxx° C	55.80	95.18	77.55	91.18	85.53	74.34	92.16
Total.....	99.74	99.23	99.65	99.72	99.18	99.54	99.78
Value of x.....	264.4	270	270	269.0	259.7	270	270
Value of xx.....	.....	312.1	315	.....	.....	315	315
Value of xxx.....	264.4	312.1	343.6	269.0	259.7	327.2	329.6

which the tars were distilled in order to attain the same amount of residue as that left on exposure. It can also be seen that, with the exception of the coke-oven tar (5123), the materials

consisting in all or part of water-gas tar had to be distilled to relatively much higher temperatures than the coal-tar products in order to obtain the desired amount of residue.

The residues obtained from the distillations described above were subjected to tests corresponding to those run on the residues obtained in the exposure box. The results of these tests, together with the corresponding results for the residues from three months' exposure, are tabulated in Table VI.

TABLE VI.

Tests on Residues from Exposure and Distillation.

Sample number	Material	Residue	Per cent. residue	Float test, 100° C.	Penetration, 25° C.	Per cent. free carbon
		Distillation to 315° C...	80.11	45″	32	25.21
3896	Refined coal-tar..	Distillation to 264.4° C..	85.80	34″	158	23.75
		Exposure 3 months.....	86.61	41″	50	23.64
		Distillation to 315° C...	95.30	53″	24	19.69
4797	Refined mixed tar.	Distillation to 312.1° C..	95.18	49″	37	20.15
		Exposure 3 months.....	96.23	55″	28	21.40
		Distillation to 315° C...	80.96	27″	142	12.94
5123	Crude coke-oven tar	Distillation to 343.6° C..	77.55	38.5″	41	12.93
		Exposure 3 months.....	78.79	47″	18	15.90
		Distillation to 315° C...	85.76	84″	5	35.50
5627	Refined coal-tar...	Distillation to 269.0° C..	91.18	68.5″	17	33.35
		Exposure 3 months.....	92.15	78″	11	33.60
		Distillation to 315° C...	77.93	114″	2	21.11
5992	Tar-asphalt mixture	Distillation to 259.7° C..	85.53	37.5″	55	19.30
		Exposure 3 months.....	87.16	48″	47	20.68
		Distillation to 315° C...	76.66	30″	107	3.80
6672	Water - gas tar preparation	Distillation to 327.2° C..	74.34	43″	68	3.30
		Exposure 3 months.....	75.82	59″	19	10.02
		Distillation to 315° C...	95.95	29″	138	1.29
X	Refined water-gas tar	Distillation to 329.6° C..	92.16	42″	66	2.36
		Exposure 3 months.....	93.33	49″	20	6.09

The comparison of the residue obtained from exposure with that from straight distillation carried to a point where the percentage of residue corresponded approximately to the former leads to the conclusion that the hardening effect of exposure is much more than can be attributed to loss by volatilization alone, and that changes in the inherent nature of bitumen take place when exposed to the prolonged action of air and sun. It is evident that the residues from exposure are harder in every case, as shown by both the penetration test and float test at 100° C., which

is more significant when we observe that the distillations were carried further than intended in all cases, the residues obtained being 0.81 to 1.63 per cent. less than the exposure residues. It is also interesting to compare the consistency of a tar residue obtained by distillation to an arbitrary temperature such as 315° C., with that of a residue obtained by exposure. It will be noted that in three cases (5123, 6672, and X) the penetration of the residue from the distillation is very materially higher than that

TABLE VII.

Percentage Free Carbon, Actual and Calculated.

Sample number	Material	Free carbon original	Residue	Actual	Calculated	Increase, actual	Increase, calculated
			Distillation to 315° C.	25.21	24.2	5.85	4.8
3896	Refined coal-tar	19.36	Distillation to 264.4°C.	23.75	22.6	4.39	3.2
			Exposure 3 months...	23.64	22.4	4.28	3.0
			Distillation to 315° C.	19.69	18.0	2.56	0.9
4797	Refined mixed tar	17.13	Distillation to 312.1°C.	20.15	18.0	3.02	0.9
			Exposure 3 months...	21.40	17.8	4.27	0.7
			Distillation to 315° C.	12.94	10.8	4.17	2.0
5123	Crude coke-oven tar	8.77	Distillation to 343.6°C.	12.93	11.3	4.16	2.5
			Exposure 3 months...	15.90	11.1	7.13	2.3
			Distillation to 315° C.	33.50	34.6	3.85	5.0
5627	Refined coal-tar	29.65	Distillation to 269.0°C.	33.35	32.5	3.70	2.9
			Exposure 3 months...	33.60	32.2	3.95	2.6
			Distillation to 315° C.	21.11	18.7	6.54	4.1
5992	Tar - asphalt mixture	14.57	Distillation to 259.7°C.	19.30	17.0	4.73	2.4
			Exposure 3 months...	20.68	16.7	6.11	2.1
			Distillation to 315° C.	3.80	3.22	1.33	0.75
6672	Water-gas tar	2.47	Distillation to 327.2°C.	3.30	3.32	0.83	0.85
			Exposure 3 months...	10.02	3.26	7.55	0.79
			Distillation to 315° C.	1.29	0.75	0.57	0.03
X	Refined water-gas tar	0.72	Distillation to 329.6°C.	2.36	0.78	1.64	0.06
			Exposure 3 months...	6.09	0.77	5.37	0.05

of the residue from the exposure, while with the other four samples the reverse is true. Consistency tests on a residue from tar which has been distilled to a single arbitrary temperature cannot therefore be looked upon as altogether sound bases for comparison. Comparing the solubilities in carbon bisulphide, we note that the residue from exposure contains a greater percentage of free carbon, except with sample 3896, where the difference is slight; that in the case of the coal-tars, numbers 3896 and 5627, the percentage of free carbon is practically the same; and that

numbers 6672 and X, refined water-gas tars, one containing a small amount of a petroleum product, show the largest difference. Table VII presents the percentages of free carbon as determined and those calculated from the original material on the basis of per cent. of residue.

In Table VII it is shown that the actual percentage of free carbon in all residues except two is greater than can be ascribed to loss of distillate alone, and that in the case of all samples except the refined coal-tars there is a large increase of free carbon over the calculated amount in residues formed from exposure.

CONCLUSIONS.

As previously noted, it is realized that the action of air and sun upon bituminous materials in their pure state, as carried on in this work, is probably very different from what it is when the material is in actual service, but our work as pursued would seem to point to the following conclusions:

1. Upon exposure to service conditions tar products materially harden to a much greater extent than can be attributed to loss of distillate alone.

2. The changes which take place other than loss of distillate are accompanied by formation of organic matter insoluble in carbon bisulphide.

3. Tar products containing water-gas tar appear to change to a greater extent than coal-tars, as indicated by the greater formation of organic matter insoluble in carbon bisulphide.

4. The comparative consistency of pitches obtained from distillations of tars to a single arbitrary temperature do not represent the relative behavior of the tars in service.

Hot Water Supply from Sunshine. ANON. (*Scientific American*, vol. cxv, No. 7, August 12, 1916.)—The hot water used by one-half of the residents of Monrovia, Calif., is heated by the sun; and many other establishments, domestic and otherwise, in other localities along the Pacific Coast are at the present time supplied with sun-heated water. The sun imparts its warmth to water exposed in a coil on the roof or at some other favorable location; and, as the temperature of the water in the coil becomes greater than that of the supply source, a circulation is set up and the warmed water moves along through the coils to a storage tank, from which it is drawn for use.

The sun coil in which the operation of heating the water takes place consists of a shallow box about four inches deep, with a copper bottom; and back and forth through this box is an arrangement of pipes through which the water passes. Copper is selected as it is the best conductor of heat, and the pipes are secured in intimate contact with the copper bottom, being soldered to it so as to secure the greatest efficiency. The box is covered with glass and placed at some point where it will receive the greatest amount of exposure to the sun's rays. The California coast seems to be the ideal place for the sunshine water heater, and most of those in use are to be found on the Pacific slope. But there is no reason why they should not be used in other sections of the country, especially through the South, where the sun is regarded as reasonably reliable in the matter of its daily visits.

Gasoline Switching Locomotive. ANON. (*Railway Age Gazette*, vol. 61, No. 6, August 11, 1916.)—The Erie Railroad has adopted a unique plan for taking care of its business in the vicinity of its Erie Street freight station in the city of Chicago. A gasoline locomotive with a hauling capacity of 500 tons distributes cars brought up the Chicago River on barges to the team and horse tracks for loading and unloading. The engine was built by the Baldwin Locomotive Works and is of the following dimensions: Weight in working order, 44,000 pounds; wheel base (4-wheel coupled), 6 feet 6 inches; length over all, 18 feet 8 inches; number of cylinders, 4; cylinder diameter and stroke, 9 inches by 16 inches; diameter of driving wheels, 42 inches. The engine is equipped with a Kingston carburetor. It has both magneto and battery ignition, two speeds, 3½ and 8 miles per hour, chain drive, the Hele-Show multiple disc type clutches for the main clutch and jaw clutches for the transmission clutch. The capacity of the gasoline tank is 35 gallons. The locomotive is equipped with an electric self-starter, headlight, and the various safety devices prescribed by the Interstate Commerce Commission for switching locomotives, modified to suit the special construction of this engine.

NEW METHOD FOR MEASURING RESISTIVITY OF MOLTEN MATERIALS: RESULTS FOR CERTAIN ALLOYS.*

BY

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AND

R. G. SHERWOOD.

THE first-named writer began an experimental investigation of the electrical conductivity of molten metals and alloys in 1911. The electrical conduction at high temperature of all forms of matter was later considered. The results of these investigations have been described in a series of papers,[1] of which five, relating to metallic conduction, have appeared in the JOURNAL OF THE FRANKLIN INSTITUTE.

To obtain accurate data from which curves may be drawn that give the relation between resistivity and temperature over a wide range of temperatures, it was found necessary to devise entirely new methods of producing the required temperature and, also, entirely new methods for measuring the resistivities of materials when in the molten state. Several different methods were developed and used in measuring the resistivities of metals and alloys.

In the paper by E F. Northrup on the "Resistivity of Copper in Temperature Range 20° C. to 1450° C."[2] the best method which had been devised prior to the date of its publication was

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* Communicated by E. F. Northrup.

The method here described is the general method devised by E. F. Northrup, modified in some of its details by R. G. Sherwood, and used by the latter for obtaining the results and all data for curves appearing in this article. E. F. N.

[1] *Trans. of the Amer. Electrochem. Soc.*, vol. XX, 1911; also XXV, 1914. *Metallurgical and Chemical Engineering*, June, 1912; May, 1913; Jan., 1914; Feb., 1914; March, 1914; May, 1914; March, 1915. JOURNAL OF THE FRANKLIN INSTITUTE, Feb., 1913; Jan., 1914; March, 1914; July, 1914; March, 1915; and "High Temperature Investigation and a Study of Metallic Conduction," June, 1015.

[2] *Journal of The Franklin Institute*, Jan., 1914.

fully described. Since that time experiments have been conducted by both writers of the present article with the view of making further improvements in the methods of measurement and of collecting additional data. Thus the method, which we describe here in full, has been reached, as it were, by a process of evolution and is, we believe, sufficiently perfected to meet every requirement of simplicity, speed, and precision. It is entirely a direct-reading and zero-method which yields all results without any calculation whatever. We shall state, therefore, rather categorically, that the details which have been shown by our experience should be observed both in the set-up of the apparatus and in the procedure to follow in taking observations. We do this because nearly every possible modification of apparatus, circuits, and manner of taking readings has been considered, and because we have been led to adopt, for one reason or another, what we here describe as being that which, all things considered, best meets requirements.

COOLING CURVES AND RESISTIVITY CURVES.

Importance has long been attached to a study of certain physical characteristics of the metals and alloys by tracing their heating and cooling curves, especially through changes in state. Melting- and freezing-point determinations are made in this way, and data for equilibrium diagrams have been taken largely from such curves. As will appear, however, from what follows, the same and additional information may be obtained, with nearly equal facility and with greater exactness, by tracing, not the progress of cooling of an element, alloy, or compound but the change in resistivity of the material with change in the temperature when this is slowly raised or lowered. The methods which have been perfected for measuring the resistivity of molten materials have enabled us in certain cases to measure simultaneously the resistivities of two metals, under identical temperature conditions, to a temperature as high as 1680° C. When, however, the temperature much exceeds 1000° C. difficulties are encountered from the formation of new chemical equilibria and the contamination of the sample being measured. Below this temperature difficulties of this character do not arise to any serious extent, and, as will appear later on, it is quite as simple to measure with high precision the resistivity of a molten metal or alloy at a temperature near 1000° C. as it is to measure the same property of mercury at room tempera-

tures. Furthermore, below 1000° C., resistivity curves can be traced with nearly the same facility as cooling curves, and they may be carried through changes of phase to low temperatures where the materials are solid.

It seems to us quite certain that data on electrical resistance or electrical resistivity of a metal, and more especially of an alloy in the solid, solid-liquid, and liquid phases, will yield new and valuable information which cannot be obtained from cooling curves or from any of the other methods now employed to study the physical characteristics of alloys.

Following the description of methods of measurement are given some results, obtained by the methods described, for alloys of tin and bismuth.

REQUIREMENTS TO BE MET.

If measurements of resistivity are to be carried higher than 1100° or 1200° C., a wire-wound furnace is unsuitable, and it becomes necessary to employ the type of furnace [3] which was developed by the first-named writer for this particular class of work. When, however, a study of the alloys is under consideration it is generally unnecessary and it is often impossible (on account of vaporization of a metal) to take observations above a temperature of 1000° C. In this case a vertical-type furnace, made by winding an alundum tube with nichrome wire or ribbon, meets every requirement. In what follows we shall confine ourselves to a consideration of measurements of resistivities which can be made in a furnace of this type.

It is necessary to measure the temperature with precision. This can be done with either a resistance-thermometer or with a thermocouple and, also, by a certain special method which will be briefly considered later. We have found a properly constructed thermocouple (its cold junction being held at 0° C. in a Dewar flask filled with cracked ice), which when read with the aid of a Leeds & Northrup potentiometer, fills every requirement of precision. A thermocouple, furthermore, gives the desired temperature-readings in the simplest and most direct manner, and, furthermore, its calibration is effected with greater ease than the calibration of other devices by checking it against the freezing-points of certain metals.

[3] "A New High Temperature Furnace," by E. F. Northrup, *Metallurgical and Chemical Engineering*, Jan., 1914.

To obtain the value of the resistivity of a molten material, it is very desirable to employ a device which will give this result by direct insertion of the device into a considerable mass of the molten material, contained in a crucible. We have named the instrument devised for this purpose a "resistometer." Its use has many advantages over the earlier devices and methods employed. Previous to the development of the resistometer a small quantity of the molten material was confined in a specially shaped form moulded from refractory material.[4] There are some objections to these earlier methods; for when a small quantity of molten material is confined in a large mass of refractory material the likelihood of contamination of the molten material by contact with its container is considerable, and moulded forms require considerable skill and labor to construct. The resistometer, on the other hand, with its small mass, when inserted in a large mass of molten material, is little to contaminate it.

The desirability of making the readings of resistivity directly in microhms per cm.$^{-3}$ and by means of a null-method requires the use of a Kelvin double-bridge, which is the best type of low resistance-reading device employed with a null-method.

Alternating current must be used for the measuring current. Our experience has demonstrated that where potential terminals come in contact with a molten metal or alloy a not inconsiderable electromotive force is always developed, and that it rapidly increases in magnitude and irregularity as the temperature increases. Above 500° C. these electromotive forces become so large and erratic that it is exceedingly difficult, and at times impossible, to make accurate measurements, if direct current is used as the measuring current. By substituting alternating current all difficulties arising from parasitic electromotive forces and currents vanish.

An alternating-current galvanometer, or other detector of balance of the bridge, which will be responsive to alternating current only and comparable in sensibility to a good D'Arsonval galvanometer, is required when the measuring current is alternating. An alternating-current galvanometer which possesses new features and fills every requirement was designed especially for this work.

In measuring the resistance of molten materials, connections

[4] "Resistivity of Copper, etc.," JOURNAL OF THE FRANKLIN INSTITUTE, Jan. 1914, see p. 7.

or electrodes must be used which shall serve both for current and potential terminals. Tungsten wire, and in many cases molybdenum wire, has proved entirely satisfactory for this purpose at the temperatures used, because neither tungsten nor molybdenum fuses or appreciably alloys with any molten metal not belonging to the iron group.

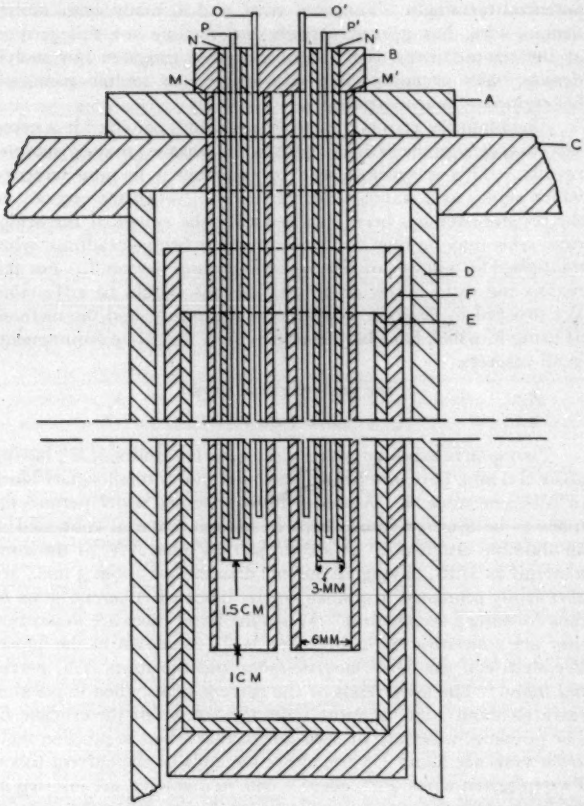
To obtain the results directly in microhms per cm.$^{-3}$ it is necessary to so design the resistometer that its constant may be obtained readily. This is accomplished by inserting it in pure mercury, which serves as a standard of resistivity. When the constant of the resistometer has been obtained thus, the values of the bridge ratio-coils may be then so chosen that the bridge-readings, when multiplied by a power of ten, are in microhms per cm.$^{-3}$. For this reason the ratio-values of two ratio-arms should be adjustable. We proceed to describe in detail the apparatus, and the methods of using it, which have been found to meet the above requirements in all respects.

THE RESISTOMETER TYPE 1.

(*See Fig.* 1.)

Two quartz tubes or Marquardt porcelain tubes MM', having about a 6 mm. bore, are firmly cemented into a small square block of Alberene stone A. A unit is thereby formed which permits the tubes to be lowered into a bath of molten material contained in an alundum crucible E. A second pair of tubes NN' of the same material as MM', having an outside diameter of about 3 mm., are also firmly cemented in a small square block of Alberene stone B, thus forming a second unit. When the latter tubes are in position they are concentric with the tubes MM', as shown in the figure. We shall call the MM' *current-tubes* and the tubes NN' *potential-tubes*. The lower ends of the current-tubes when in position reach to about 1 cm. or more from the bottom of the crucible E. The potential-tubes are of such length that when in position their lower ends are about 1.5 cm. above the ends of the current-tubes. Two tungsten wires, PP', about 1 mm. in diameter, are inserted in the potential-tubes and extend to 1 or 2 mm. from the ends of these tubes. Two other tungsten wires, OO', preferably of a little larger diameter, are inserted in the current-tubes and lie alongside the potential-tubes. The lower ends of these wires should be 0.5 cm. or more above the ends of the potential-tubes. These latter

FIG. 1.



wires constitute the current-leads and the former the potential-leads.

The sample contained in the crucible *E* should be sufficient in quantity to reach a little above the lower ends of the current-

terminals. Molybdenum may in many cases be substituted for tungsten for the current- and potential-leads. Tungsten is, however, to be preferred if the temperature is to be carried very high. In one experiment a No. 20 tungsten wire and a No. 20 molybdenum wire were placed in molten tin held at 1200° C. for about fourteen hours. The molybdenum wire had dissolved to an extent that reduced it in size to No. 23 B. and S., while the tungsten wire had not perceptibly changed in diameter. Little action is to be expected on either tungsten or molybdenum immersed in any metal or alloy which is molten and under 1000° C.

As shown in Fig. 1, the crucible *E* is placed in a container, *F*, made of Acheson graphite. The main object in using the graphite container is to obtain a reducing atmosphere in the furnace, and incidentally, also, to more uniformly distribute the heat about the crucible *E*. When the chamber of the furnace is filled with a reducing atmosphere the surface of metals which readily oxidize in an oxidizing atmosphere is maintained free from oxide and bright. It is specially important to maintain a reducing atmosphere when working with copper, as this metal dissolves the oxide which forms on its surface and so changes in specific resistance.

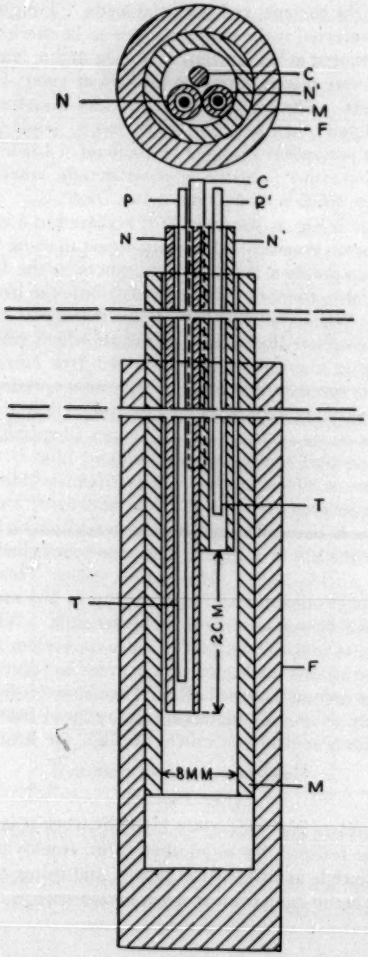
The heater-unit consists of an alundum tube *D* wound with nichrome wire or ribbon. This wire or ribbon winding may with advantage be covered over with alundum cement or "Vulcan paste," which helps to hold the winding securely in position on the alundum cylinder on which it is wound. The alundum cylinder is firmly cemented in a heavy slab, *C*, of Alberene stone. This slab, which may be round or square, also forms the top of any metal or other gas-tight vessel chosen to contain the heater-unit. When working at temperatures under about 500° C. it is convenient to have only air insulation around the heater-unit in order to secure rapid cooling when the current is turned off. When slow cooling is desired this is readily secured by maintaining a reduced heating current, adjusted with a control resistance, through the heater-unit.

THE RESISTOMETER TYPE 2.

(*See Fig. 2*)

In many cases and for certain kinds of work it is desirable to construct the resistometer in another form, employing, however, the same principle as that used in type 1, and using it in the same circuits and in the same manner when measurements of resistivity

FIG. 2.



are made. In this form a single tube, M, only is used, which has approximately the same dimensions and is made of the same material as either one of the tubes of type 1.

Two potential-tubes, *NN'*, firmly cemented together with Vulcan paste, are arranged so that they will readily enter this outside single tube. One of these potential-tubes is longer than the other by 1.5 cm. to 2 cm. When the potential-tubes are in position the lower end of the longer one may reach within a few millimetres from the bottom of the outside tube, *M*, which we designate the *current-tube*. This latter is inserted in a tube, F, of Acheson graphite closed at the bottom. The current-tube may reach a short distance from, or quite to, the closed bottom of the graphite-tube *F*. The sample the resistivity of which is to be measured is poured while molten into the graphite-tube and the current-tube is then inserted, the molten material filling the interior of the current-tube to a level chosen a short distance above the lower end of the shorter potential-tube *N'*.

One current-lead *C* of tungsten or molybdenum is placed alongside the potential-tubes, its lower end being maintained a little above the lower end of the shorter potential-tube. The graphite-tube or casing forms the second current-lead.

When current is passed through the resistometer there is a drop in potential between the lower end of the shorter and the lower end of the longer potential-tube. There is inserted in each of the potential-tubes a tungsten wire, *T*, which reaches to within a millimetre or two from the lower end of each of these tubes. These potential-leads serve as a means for measuring this potential drop. If the two potential-tubes are firmly cemented together, then the distance between their ends,—that is, the distance between potential-points,—is fixed, and if the two potential-tubes occupy the same position in the current-tube at the time the constant of the resistometer is obtained by measuring its resistance when filled with pure mercury as when measuring its resistance when filled with the molten metal, the resistivity of this latter is to the resistivity of pure mercury as the measured resistance of the latter is to the measured resistance of the mercury. In other words, the cross-section and length of the fluid-column of which the resistance is measured is invariant, because the very slight expansion with temperature of the Marquardt porcelain or quartz of which the current- and potential-tubes are made is quite negligible.

If the lower potential-terminal ends 3 or 4 mm. above the end of the current-tube it is immaterial whether the current-tube reaches to the bottom of the graphite casing or not. All parts of this type of resistometer, current-tube, potential-tubes, tungsten wire potential-leads, and current-lead should be aranged so as to be readily assembled and taken apart because, after the resistometer has been filled with pure mercury for obtaining its constant, it must be freed from the last traces of mercury, which tend to cling to the potential-tubes, before filling it with molten metal or alloy.

The advantages of this single-tube type of resistometer consist largely in its simplicity and compactness and in the fact that it is better adapted than the former type to the measurement of the resistivity of a precious metal or an alloy of precious metals, where, for reason of cost, it is desirable to use small quantities of metal. Again, this type of resistometer when filled with pure molten tin can be used as a pyrometer which will measure temperatures up to 1600° or 1700° C. As has already been shown by the first writer in a previous paper,[5] tin increases linearly in resistance from its melting-point (232° C.)to at least 1680° C., and hence can be used in a resistometer as a pyrometric substance. A measurement of the resistance of the tin contained in the resistometer need only be made at two known temperatures to obtain the calibration of the resistometer, used as a pyrometer up to a temperature of at least 1680° C.

On the other hand, this second type of resistometer is less desirable than the first when one has in view the tracing of the resistivity curves of base metals or their alloys. The first type can be made more robust and is more easily cleaned, as it must be when used with different samples, and the vertical distance of the liquid column the resistance of which is measured can be made less than in the second type, a circumstance which insures greater uniformity of temperature in the mass of metal being measured.

In either type of resistometer it is important that the thermocouple should have its hot junction in as close proximity as possible to the column or columns of molten metal contained between the potential-points when the resistance is being measured. In using resistometer type 1, the thermocouple can be immersed with

[5] JOURNAL OF THE FRANKLIN INSTITUTE, June, 1915, p. 625.

the resistometer in the same bath of molten material, and by placing it alongside of and between the two current-tubes the temperature of the columns of material being measured is given with great exactness. When resistometer type 2 is used, it is desirable to submerge the graphite-casing of this, and the thermocouple in close contact with it, in a bath of molten tin. By so doing the temperature will be sensibly the same at the end of the thermocouple and in the interior of the resistometer. We recommend for most classes of work type 1 in preference to type 2.

ALTERNATING-CURRENT GALVANOMETER.

As previously stated the large electromotive forces of a parasitic character which are developed in the resistometer, when this is immersed in a molten metal or alloy, preclude the use of direct current for the measuring current and, therefore, a direct-current galvanometer. We have worked with both 60-cycle and 25-cycle alternating current. The latter is to be preferred, as it is then of less importance, when high precision is required, that the ratio-coils in the Kelvin double-bridge should be free from capacity or inductance. The alternating-current galvanometer which has been designed, two of which were constructed for this work in the shop of the Palmer Physical Laboratory, has proved a very great success and completely fulfils the following requirements for a satisfactory instrument:

The sensibility of the instrument should be fully equal to the sensibility of a good D'Arsonval galvanometer of the type of a Leeds & Northrup "High Sensibility Narrow-coil Galvanometer," known as catalogue No. 2294 and described in the Leeds & Northrup catalogue No. 20. In fact, it was aimed to give the alternating-current galvanometer the same characteristics in performance as this direct-current instrument. The sensibility, however, of the alternating-current galvanometer is not a constant quantity as with a direct-current instrument, but may be varied to any degree within wide limits by simply changing the value of the alternating-current passed through its magnetizing coils. As the damping of the system varies with the square of the field-strength, this latter is chosen of such value, by adjusting the current through the magnetizing coils, that the system after deflection returns aperiodically to zero with the particular resistance in circuit with the swinging coil which is in use. With an adjustment of field-

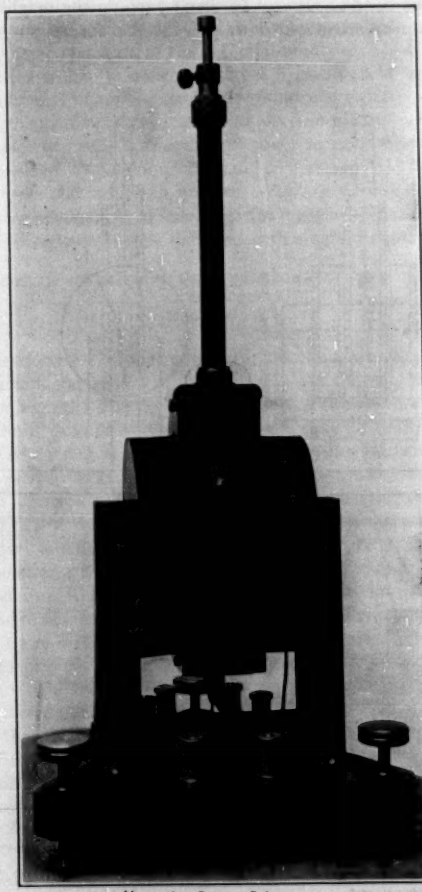
strength made thus, the sensibility of the galvanometer should equal that of the direct-current instrument referred to. The aperiodic time of swing of the galvanometer should not exceed two or three seconds, and this requirement makes it necessary to use a narrow, light coil for the swinging system. In fact, the swinging system used was identical with that used in the Leeds & Northrup galvanometer just referred to.

When the alternating-current galvanometer is in use the swinging system is necessarily on closed circuit, and, as this latter hangs in a field in which the magnetic flux is alternating, currents are induced in the swinging-coil circuit. It is essential that these induced currents should not cause the system to seek a position of stable equilibrium other than that at which it comes to rest when no currents are flowing. This requirement has been fully met by the special shape which has been given the pole-pieces of the laminated galvanometer-magnet. It has never been found necessary to make any phase adjustments of any of the currents.

The magnetizing coils, two in number, may be joined in series or parallel combination. They are always connected *in series* with the main circuit of the Kelvin double-bridge, and hence must be able to carry without heating and without too strongly magnetizing the magnet, a current which is at least as large as the current passed through the bridge. It is unadvisable to cut down the current through the magnetizing coils, which are highly inductive, by means of a shunt. The bridge, however, being non-inductive, may be shunted to any extent. Hence it follows that the current through the magnetizing coils required to energize the field-magnet may be chosen much larger than, but never less than, the current which is passed through the bridge.

The general appearance of the galvanometer is given in Fig. 3, reproduced from a photograph, while Fig. 4 shows a few details of construction. In referring to Fig. 4 it will be noted that the fixed iron core-piece between the pole-faces, which is generally used with direct-current instruments, is omitted. The pole-faces are hollowed out so that the coil swings in a hollow cylinder. This construction is used for the reason that when the coil is on short circuit it will tend to set itself in the weakest part of the field. The shape which has been given the pole-pieces makes the position of stable equilibrium for the system that which corresponds to zero reading on the scale.

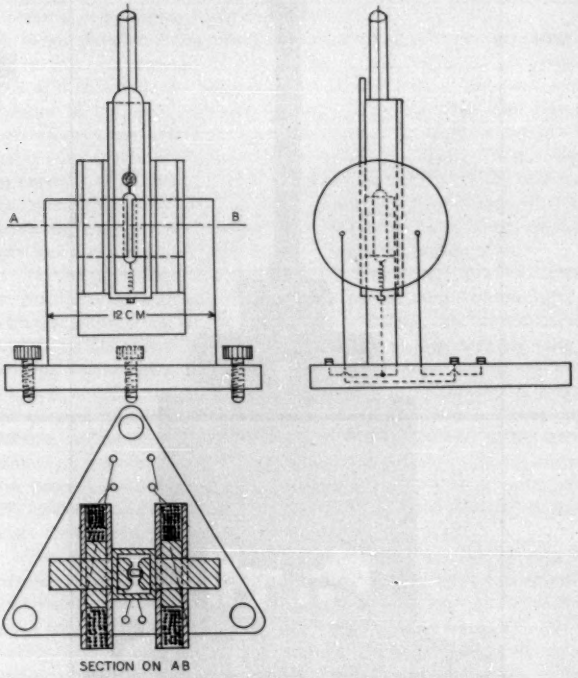
FIG. 3.



Alternating Current Galvanometer

The system hangs in a box of hard rubber with a glass front which exposes it to view. All metal parts in the neighborhood of the system are avoided to prevent the formation of eddy currents.

FIG. 4.



When adjustments are properly made the performance of this instrument with current of 25 cycles or 60 cycles is in all respects like that of a quick-acting, aperiodic, highly-sensitive direct-current instrument.

THE KELVIN DOUBLE-BRIDGE.

It is very much more convenient for work of this class to employ a type of Kelvin double-bridge in which a balance is obtained by varying the position of the potential-points on a low-resistance standard than one in which a balance is obtained by varying the ratio-coils and using a fixed low-resistance standard. The type of variable low-resistance standard used in all our work is the one made by Leeds & Northrup known as catalogue No. 4300 and described in catalogue No. 40, p. 7 *et seq.** The variable ratios were obtained with an Otto Wolff box, designed for use with low-resistance fixed standards for measuring low resistances. The fixed ratio-coils were obtained with single-resistance units.

CIRCUIT-CONNECTIONS, USING RESISTOMETER TYPE 1 AND A THERMOCOUPLE.

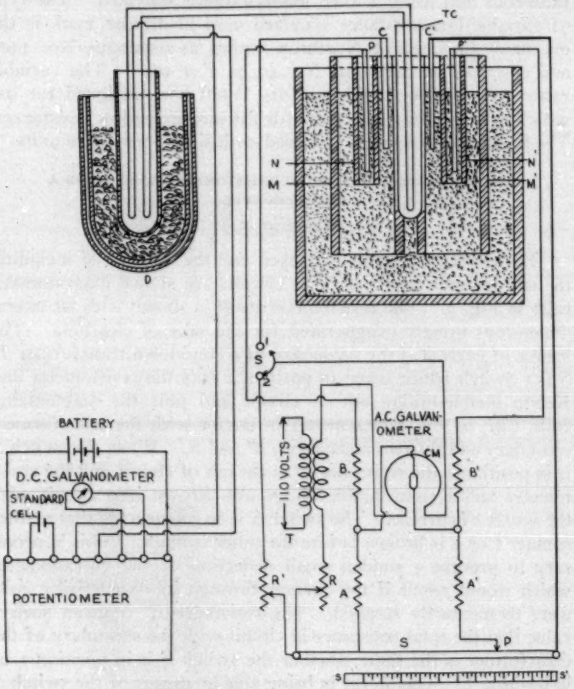
(*See Fig.* 5.)

The electrical circuits employed and the manner of including the resistometer type 1 in these circuits are shown diagrammatically in Fig. 5. The resistometer itself is shown with its lateral dimensions greatly exaggerated for the sake of clearness. The source of current is the secondary of a step-down transformer T. S is a switch which when in position 2 cuts the resistometer and Kelvin double-bridge out of circuit and puts the magnetizing coils, CM, of the galvanometer in circuit with the transformer-secondary and the two resistances, R' and R. When the switch S is in position 1 the resistance R' is cut out of circuit and the resistometer and Kelvin double-bridge are thrown into circuit with the source of current. The switch S is so constructed that neither contact 1 or 2 is broken before the other is made. This is necessary to prevent a sudden small deflection of the galvanometer which would result if the current through its magnetizing coils were momentarily stopped. The resistance R' is given such a value that the total resistance in circuit with the secondary of the transformer is the same whether the switch S is in position 1 or in position 2. The object in being able by means of the switch S to throw the bridge and resistometer out of circuit is, that by so doing the zero position of the galvanometer may be located. Re-

* For full treatment of the theory and use of the Kelvin double-bridge, see Northrup, "Methods of Measuring Electrical Resistance," McGraw-Hill Book Co., 1912. *Arts.*, 609-612.

sistances A and A' are fixed ratio-coils, generally chosen 1000 ohms each. Resistances B and B' are ratio-coils which can be varied. They are chosen of such a value that the settings of the slider P, as read on the scales S, S' shall indicate the resistivity of

FIG. 5.



the sample, when multiplied by some power of ten, in microhms per cm.$^{-3}$. In our work we used the set of Otto Wolff ratio-coils above referred to for obtaining the required resistance values of B and B'. The method of finding the proper values for B and B', to make the bridge read directly resistivity in microhms will be explained later.

The thermocouple, *TC*, is located in the bath of molten material so that its hot junction is midway between the bottom ends of the two potential-tubes, *N N'* and the two current-tubes *M M'*. Its cold junction is located in the Dewar flask *D*, filled with cracked ice, and the terminals of copper wire which lead from the cold junction are joined to the potentiometer as shown in Fig. 5. Our work was all done with a Leeds & Northrup potentiometer, catalogue No. 7551, described in catalogue No. 70.

CIRCUIT-CONNECTIONS, USING RESISTOMETER TYPE 2 AND A TIN-PYROMETER.

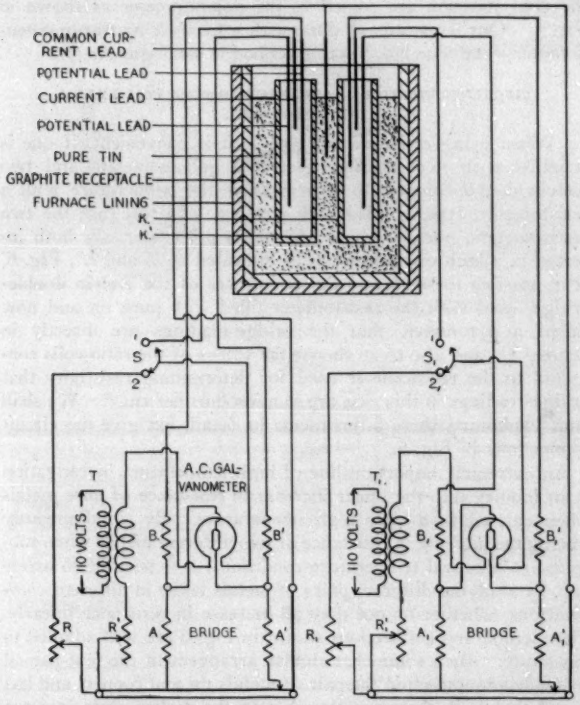
When using resistometer, type 2, it is convenient, if one is supplied with two alternating-current galvanometers and two Kelvin double-bridges, to also measure the temperature with a resistometer, type 2, filled with pure tin. In this case the two resistometers, one of which becomes a pyrometer, are both inserted in a bath of molten tin, as indicated at *K* and *K'*, Fig. 6. It is possible to so choose the resistances of the Kelvin double-bridge, used with the resistometer filled with pure tin and now called a pyrometer, that the bridge-readings are directly in degrees C., and also to so choose the values of the ratio-coils connected to the resistometer used for determining resistivity that bridge-readings in this case are in microhms per cm.[3]. We shall omit explaining these adjustments in detail, but give the circuit connections in Fig. 6.

An extremely important line of high-temperature investigation is an inquiry into the linear increase in resistance of pure metals when carried to a very high temperature. By simultaneously tracing the increase in resistance of two different metals when subjected to identical temperature-conditions, it is possible to ascertain, by studying different pairs of metals taken in different combinations, whether or not they all increase in resistance linearly. The method and connections shown in Fig. 6 are well adapted to this study. By a somewhat similar arrangement the first-named writer has investigated the pair of metals tin and copper[6] and has found that both these metals when in the molten state increase linearly in resistance to at least 1680° C. The second-named writer made this comparison also between the metals lead and tin by using the apparatus and method shown in Fig. 6 and found,

[6] JOURNAL OF THE FRANKLIN INSTITUTE, June, 1915, p. 635.

likewise, that both tin and lead increased linearly in resistance when molten up to about 1575° C. We believe that the method devised, as shown in Fig. 6, is most convenient for direct comparison to a very high temperature of the rate of increase in resistance

FIG. 6.

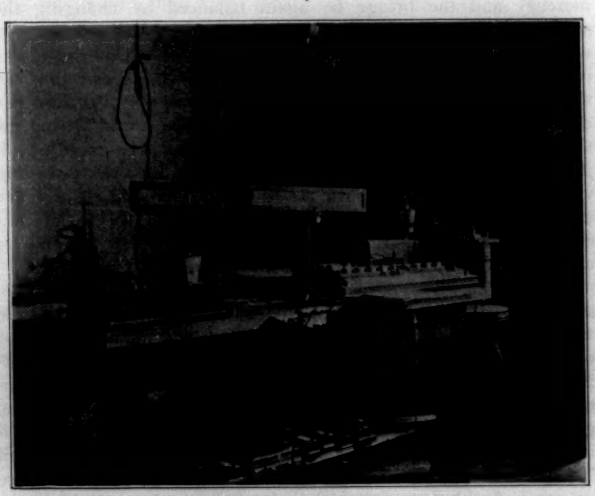


of two molten metals or alloys. If this comparison were to be made of various pairs of metals chosen in different combinations *it would firmly establish an extension, to a high temperature, of the temperature-scale on a basis new and quite as reproducible as the gas-scale.*

CALIBRATION OF RESISTOMETER; ADJUSTMENT OF RATIOS.

The theory of the method of adjusting the ratio-coils in a Kelvin double-bridge so that the readings on the variable low-resistance standard when multiplied by a power of ten will be in microhms per cm.$^{-3}$ has been given by the first-named writer in a former paper.[7] The calibration of the resistometer and the adjustment of the ratio-coils, however, may be determined experi-

FIG. 7.



Assembled apparatus used in measurements

mentally and simultaneously without any calculation, in the simplest manner possible, as follows:

A container of the same dimensions as the one destined to contain the sample is filled with pure mercury. The resistometer is placed in this mercury, the temperature of which is accurately taken with a mercury thermometer. The two ratio-coils *A A'* (Fig. 5) are given some arbitrary value, say 1000 ohms. A set-

[7] "Resistivity of Copper in Temperature Range 20° C. to 1450°," JOURNAL OF THE FRANKLIN INSTITUTE, Jan., 1914, pp. 9–11.

ting is then made on the variable low-resistance standard which when multiplied by some power of ten is equal to the specific resistance of the mercury in ohms when at the temperature recorded. A balance of the bridge is then effected by the simultaneous adjustment of the ratio-coils $B\,B'$. The readings of the bridge when multiplied by the proper power of ten will now give the resistivity of the mercury in microhms per cm.$^{-3}$. Likewise, if a molten metal of unknown resistivity be substituted for the mercury and the bridge be again balanced by changing the setting on the variable low-resistance standard the new setting, when multiplied by the same proper power of ten, is the resistivity of the molten metal. For example: if the mercury has the temperature of 25° C. its resistivity is 96.268 microhms per cm.^{3} Choosing the ratio-coils $A\,A'$, 1000 ohms, and setting the variable resistance at 0.009628 ohm, the bridge is balanced by adjusting the ratio-coils $B\,B'$. It is evident that the bridge-reading when multiplied by 10^4 is the resistivity in microhms of mercury at 25° C., and it is obvious that, the ratio-coils being left unchanged, all bridge-readings henceforth, whatever sample is chosen, will give the resistivity of this in microhms per cm.$^{-3}$.

By making these adjustments the resistivities of the samples studied are determined without any calculation whatever, and the result is that it is actually simpler to measure the resistivity of molten brass, for example, at 800° C. than to determine the resistivity of a rod of metal at room temperature. When the resistometer-tubes are made of Marquardt porcelain the temperature, given a suitable furnace, can be carried to 1600° or 1700° C., and it follows that, when one is supplied with the equipment which has been described, the resistivities of molten metals can be determined with the greatest ease, simplicity, and accuracy to even this high temperature.

MANIPULATION.

Before beginning a series of observations a test should be made of the measuring apparatus to ascertain if any defects exist in the circuits, such as incorrect connections, bad contacts, poor insulation, etc. For making this test the ratio-values of the bridge are set close to the values which are to be used in the measurements, and the same current- and potential-leads, which attach to the resistometer, are connected to a low-resistance standard of

manganin. A standard should be selected which has a resistance not far from the average resistance of the resistometer. The resistance of this manganin standard is then measured, a balance being obtained by varying the setting on the low-resistance standard. If a correct resistance value is now obtained for the manganin standard-resistance, one is assured that the bridge and measuring circuits will yield correct results when used to measure the unknown resistance of the resistometer. In fact, by this procedure the determination of the unknown resistance is reduced, almost, to a substitution method of measurement, and the chance of introducing a systematic error into the resistance-measurements becomes practically nil.

There is one important precaution which requires consideration, if high precision is desired. This consists in so selecting the values of the ratio-coils $A\ A'$ that when the resistance values of the ratio-coils $B\ B'$ are correctly chosen in the manner previously described, these latter values will be very large in comparison with the resistance of the tungsten or molybdenum potential-leads. The reason for this depends upon the fact that, so much of these leads as are in the lower end of the resistometer, change in resistance when the temperature of the resistometer is changed. By making the resistances of $B\ B'$ very large in comparison with this variable resistance of the potential-leads, the per cent. variation in the ratios B/A and B'/A' may be made quite negligible under all variations in temperature.

It is not improbable that on first heating a sample in a crucible some contaminating material may be dissolved out of the substance of the crucible and so affect the resistivity of the sample. To guard against this possibility it is well to first heat in the crucible to be used some of the sample material, carrying the temperature higher than one intends to carry it in making measurements. This first lot of sample material is then replaced by a fresh lot, when it may be safely assumed that the first lot of material has taken up all contamination from the crucible and that the second lot will not take up any contamination, and hence may be used for the sample to be measured. After a test on a sample has been completed it becomes necessary to thoroughly free the resistometer from all traces of the material tested before it can be used for testing another sample of a different kind. If the sample tested has a melting-point lower than the boiling-point of mercury

and is soluble in mercury, the resistometer may be easily cleaned by immersing it in hot mercury until all traces of the sample tested are dissolved off the tubes and metal terminals. Any mercury which clings to the parts of the apparatus is easily wiped off with a cloth. If the material to be removed has a higher melting-point than boiling mercury or does not readily dissolve in mercury, it may still be removed by first immersing the resistometer in molten tin, carried to the necessary temperature to dissolve the material to be removed, and then later remove with hot mercury the tin which remains.

Either type of resistometer may be used as a pyrometer for temperatures up to 1600 to 1700° C. Type 2, however, is better adapted to this service. It is very advantageous to so calibrate and employ it that the readings on the variable low-resistance standard of the Kelvin double-bridge will be (with the subtraction of a single constant) in degrees of temperature.

The following affords a simple and wholly satisfactory method of calibrating the resistometer and evaluating the constants:

Assume that a metal is selected for the pyrometric substance which is molten over the range of temperature to be measured, and that the resistance of this metal, when molten, is a linear function of the temperature. Then calling R_t the resistance at temperature t and R_o the resistance at 0° C. of this metal between potential-points of the resistometer, we can write,

$$R_t = mt + R_o \quad \ldots\ldots (1)$$

where m is a constant and t is the temperature.

By the law of the Kelvin double-bridge,

$$R_t = \frac{b}{a} S \quad \ldots\ldots (2)$$

where S is the reading of the bridge on the variable low-resistance standard and b/a is the ratio-setting used. Then from Equations (1) and (2)

$$\frac{b}{a} S = mt + R_o$$

from which

$$t = \frac{b}{ma} S - \frac{R_o}{m} \quad \ldots\ldots (3)$$

The value of the resistance a may be chosen arbitrarily and the

values of m and R_o may be obtained by experiment, in the manner presently to be described, and $\frac{R_o}{m}$ will equal some constant K. When, therefore, m, a, and K are known, the resistance b can be given a value such that $\frac{b}{ma} = 10$, where 10^x is any desired power of 10. When this particular value is assigned to b, Equation (3) becomes

$$t = S\,10^x - K \quad \ldots\ldots (4)$$

Equation (4) states that the temperature will be given directly in degrees when the reading of the variable low-resistance standard is multiplied by some power of 10 and a constant quantity subtracted from the result. The power of 10 to use will depend upon the resistance-range of the variable low-resistance standard employed. The multiplier of S is 10^5 if the resistance-range of the standard is from 0 to 0.01 ohm. To evaluate the constants m and R_o in Equation (1) it is, of course, only necessary to obtain experimentally the resistance of the resistometer at any two known temperatures where the metal, used as a pyrometric substance, is molten. Thus according to Equation (1) we have for a temperature t

$$R = mt + R_o \quad \ldots\ldots (5)$$

and for temperature t_1

$$R_1 = mt_1 + R_o \quad \ldots\ldots (6)$$

From Equations (5) and (6) we easily derive

$$m = \frac{R - R_1}{t - t_1},$$

$$R_o = \frac{R_1 t - R t_1}{t - t_1} \quad \text{and}$$

$$\frac{R_o}{m} = \frac{R_1 t - R t_1}{R - R_1} = K, \text{ a constant.}$$

The best method of obtaining the two resistance-values of the pyrometer R and R_1 at the two temperatures t and t_1 may be applied as follows:

Select generous quantities of two metals, as lead and copper, the freezing-points of which are accurately known. Then place the pyrometer in a bath of one of these metals and record its

resistance as the metal slowly cools. When the metal begins to freeze its temperature holds constant at the freezing-point temperature of the metal for an appreciable time, and likewise the resistance of the pyrometer holds constant over this same period. This resistance is then the resistance of the pyrometer at the known freezing temperature of the metal used, and the quantities R and t become known. Repeat with the other metal, and then the quantities R_1 and t_1 become known. Curve 3, Plate IV, shows a resistance cooling curve taken in the above manner with the pyrometer placed in a lead-bath. It should be noticed how marked is the freezing-point.

The freezing-points on similar curves for Sb, Cd, Zn, and Cu, all of which may be used to give fixed points of temperature, are even more sharply defined, and hence it is easily seen how very accurately the necessary data may be obtained for determining the constants m and R_0. In making these determinations it is advisable to use crucibles made out of Acheson graphite. They are easily constructed by drilling out, with about a one-inch drill, a rod of graphite. The walls of the crucible should not be over one or two millimetres thick, because the heat capacity of the container should be kept as small as possible. If the heat capacity of the container and pyrometer are large in comparison with the heat capacity of the metal that constitutes the bath, then if the metal is one which on starting to freeze, undercools, the temperature will not ascend again to the normal temperature of solidification. The reason for this is that heat will be taken from the bath by the container and the pyrometer while the metal is rising from its undercooled temperature to its normal freezing-point temperature. The use of a thick-walled crucible, rapid cooling of the furnace, and insufficient quantity of metal in the bath, all contribute especially in the case of antimony, which greatly undercools, toward an inaccurate determination; the temperature given to the pyrometer, at the time its resistance is recorded as momentarily constant, being lower than the true freezing-point temperature.

As an illustration of the above method of calibrating a pyrometer we record the data obtained in a particular case. The pyrometric substance employed was pure tin. This metal was chosen because it is inexpensive, its melting-point is low (232° C.) and its boiling-point very high (over 2000° C.), and because its

increase in resistance with temperature, when in the molten state, is strictly linear to at least 1680° C. and probably higher. From data taken we have:

R (resistance of pyrometer at freezing-point of copper, 1082.8° C.) = 0.0021544 ohm.

R_1 (resistance of pyrometer at freezing-point of antimony, 630° C.) = 0.0018252 ohm.

Substituting these values in the expression for the value of m gives,

$$m = \frac{0.0021544 - 0.0018252}{1082.8 - 630} = 7.268 \times 10^{-7}$$

and in the expression for R_0 gives,

$$R_0 = \frac{0.0018252 \times 1082.8 - 0.0021544 \times 630}{1082.8 - 630} = 1.367 \times 10^{-3}$$

and

$$\frac{R_0}{m} = 1880 = K.$$

From the expression $\frac{b}{ma} = 10^x$ we obtain, by giving to x the value 5 and to a the value 2×10^3 ohms,

$$b = ma\ 10^5 = 7.268 \times 10^{-7} \times 2 \times 10^3 \times 10^5 = 145.36 \text{ ohms.}$$

Hence, using this pyrometer with the above constants and a variable low-resistance standard, which has an upper limit for the value S of 0.1 ohm, we obtain, according to Equation (4),

$$t = S\ 10^3 - 1880, \text{ degrees Centigrade.}$$

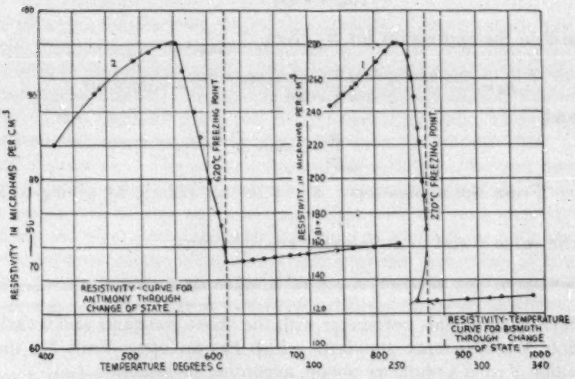
If the upper limit of S had been 0.01 ohm it would have been necessary to use the factor 10^6 instead of 10^5, and then b would have been 1453.6 ohms instead of 145.36.

When employing the resistance as a pyrometer we used the variable low-resistance standard belonging to a Leeds & Northrup Kelvin double-bridge, catalogue No. 4307, the upper limit of which is 0.1 ohm, and when using the resistometer for resistivity measurements we used a Leeds & Northrup variable low-resistance standard, catalogue No. 4300, which has an upper limit of 0.01 ohm.

OBSERVATIONS AND RESULTS.

The second-named writer, in the course of an investigation undertaken for the purpose of studying the electrical resistivity of some pure metals and also of some alloys, as these slowly changed from the liquid phase to the solid phase, and *vice versa*, has obtained some results which will serve to illustrate the usefulness and precision of the methods of measurement which have been described. It is hoped that these results, furthermore, will prove to have an interest of their own, although what is here

PLATE I.


RESISTIVITY IN MICROHMS PER C.M.³
TEMPERATURE DEGREES C
RESISTIVITY-CURVE FOR ANTIMONY THROUGH CHANGE OF STATE
630° C. FREEZING POINT
RESISTIVITY IN MICROHMS PER C.M.³
270° C. FREEZING POINT
RESISTIVITY-TEMPERATURE CURVE FOR BISMUTH THROUGH CHANGE OF STATE

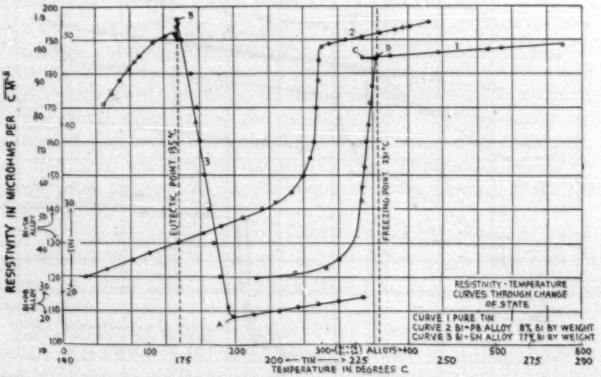
given is more or less limited in character and scope, because the research is necessarily an extended one and was only well begun at the time this article was prepared.

Curve 1, Plate IV, is a resistivity-temperature curve drawn from data obtained for pure Kalhbaum lead. The resistivity measurements were made with a type 2 resistometer, while another resistometer of the same type was used for the temperature-measuring device. This latter was filled with pure tin, which served as the pyrometric substance. The arrangement of apparatus used is shown diagrammatically in Fig. 6.

Curve 2, Plate IV, is a curve of the same character for the alloy bismuth-tin in atomic proportions. Attention is called to

the upper portion of this curve, where it will be noticed there is a sharp change, beginning at about 1140° C., from its otherwise linear character. This, very probably, is to be interpreted as the temperature at which the bismuth starts to vaporize and pass off, thus modifying the composition of the alloy. In this connection attention is directed to a phenomenon of the same character observed by the first-named writer in brass, an alloy of zinc and copper.[8] The resistivity curve of brass shows a marked inflection at about 1090° C., at which temperature the zinc began to

PLATE II.

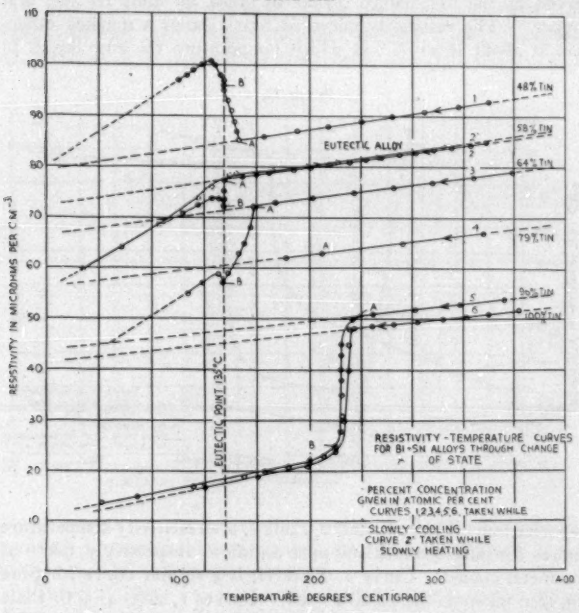

RESISTIVITY IN MICROHMS PER CM.³
EUTECTIC POINT 135°C.
FREEZING POINT 231°C.
RESISTIVITY - TEMPERATURE CURVES THROUGH CHANGE OF STATE
CURVE 1 PURE TIN
CURVE 2 Bi+Pb ALLOY 8% Bi BY WEIGHT
CURVE 3 Bi+Sn ALLOY 77% Bi BY WEIGHT
TEMPERATURE IN DEGREES C.

vaporize out. Curves 1 and 2, Plate I, are resistivity-temperature curves for pure bismuth and pure antimony respectively, taken as the metal cooled. Curve 1, Plate II, is a similar curve for pure tin, also taken as the metal cooled. Curves 1, 2, 3, 4, 5, 6, Plate III, and Curve 3, Plate II, are resistivity-temperature curves for various alloys of bismuth and tin. The per cent. of each component, in each of the different alloys used, is designated in connection with each of the curves. Curve 2, Plate II, is a resistivity-temperature curve of a Bi-Pb alloy containing 8 per cent. by weight of Bi.

[8] *Metallurgical and Chemical Engineering*, March, 1914, p. 161.

In all the above cases the resistivity measurements were made using a type 1 resistometer. The temperature measurements were all made with a copper *versus* constantan thermocouple, except with antimony, in which case a platinum-rhodium couple was employed. The hot junction of the copper-constantan couple

PLATE III.



was encased in a thin-walled quartz-tube and immersed in the sample and laid close alongside the resistometer-tubes, as previously described. The calibration of this thermocouple was carefully checked at frequent intervals during the investigation and no change in its calibration was observed. Before taking any observations on an alloy care was used to thoroughly mix the sample when at a temperature of 600–700° C. This precaution

was taken to give assurance that perfect homogeneity was secured throughout the entire mass of the sample contained in the crucible E.

DISCUSSION AND DEDUCTIONS.[1]

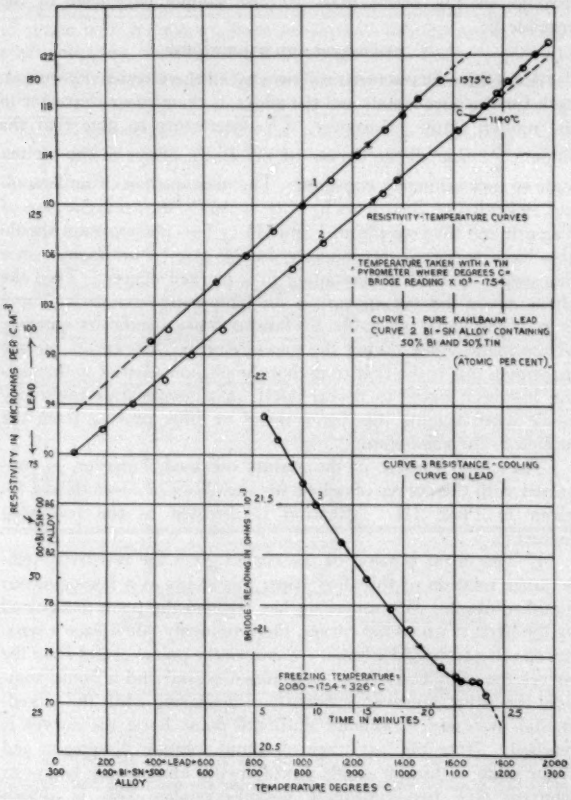
A common characteristic shown by all these resistivity-curves, both for the pure metals and the alloys, is their linear character in the molten state. Moreover, it is interesting to note that the slope $\frac{dR}{d}$ for all the curves of the Bi-Sn alloys in the molten state is approximately constant. The phenomenon of undercooling, indicated on the curves by *C D*, is clearly shown in the case of bismuth and tin (see Plates I and II). This phenomenon should also have appeared, presumably, in the case of antimony, since this metal exhibits undercooling in a marked degree. That the phenomenon did not appear on the temperature-resistivity curve is to be explained, probably, by failure to use a sufficient quantity of the metal when taking the measurements. So far as we are informed, this is the first time that the phenomenon of undercooling has been made to reveal itself on a temperature-resistivity curve when tracing this for a metal or alloy passing from the molten to the solid state.

The chief interest in the results obtained, however, is connected with the curves obtained for the alloys of bismuth and tin given in Plate III. Attention is directed to the following features:

1. The linear portion of the curves gives the resistivity-temperature relation of the alloy when this exists as a homogeneous liquid-solution. When cooling has reached the point designated by the letter *A* on all the curves, there suddenly takes place a separating out of a mixed crystal. Between the points *A* and *B* on the curves the alloy consists of this mixed-crystal and a liquid solution, the latter, however, gradually disappearing while the mixed-crystal increases in amount until the point *B* on the curves is reached. Here the last trace of liquid solution disappears and at the same instant the single mixed-crystal immediately begins to separate into two conjugate mixed-crystals. This is shown sharply on the curves. The remaining portion of the curve gives the resistivity of the alloy while the two mixed-crystals

[1] All that follows is contributed by and is entirely based on the work done by R. G. Sherwood.

PLATE IV.


RESISTIVITY IN MICROHMS PER C.M.³
LEAD
ALLOY
TEMPERATURE DEGREES C.
ALLOY
TIME IN MINUTES
BRIDGE READING IN OHMS × 10⁻³
RESISTIVITY-TEMPERATURE CURVES
TEMPERATURE TAKEN WITH A TIN PYROMETER WHERE DEGREES C= BRIDGE READING X 10³ - 1754
CURVE 1 PURE KAHLBAUM LEAD
CURVE 2 BI-SN ALLOY CONTAINING 50% BI AND 50% TIN
(ATOMIC PER CENT)
CURVE 3 RESISTANCE - COOLING CURVE ON LEAD
FREEZING TEMPERATURE = 2080 - 1754 = 326° C
1575°C
1140°C

gradually change their relative composition, as the cooling progresses. The temperature at which the last trace of the liquid solution disappears and the two mixed-crystal formation begins is, for this class of alloys, always at the definite

fixed-temperature called the "Eutectic Point." The reason why Curve 5, Plate III, does not exhibit this common characteristic is to be explained by the fact that the proportion of the constituents is such that, after the point *B* is reached, the single mixed-crystal remains as an unsaturated solid-solution of bismuth in tin, for the lowest temperature recorded. Hence there is no breaking up of the alloy into the two conjugate solid-solutions or mixed-crystals above referred to. In the case of the curve for the eutectic alloy the points *A* and *B* are at the same temperature, since, by definition of the eutectic, the homogeneous liquid solution at its freezing-point does not pass into a single mixed-crystal, as do the other alloys, but passes immediately into two conjugate mixed-crystals. The character of the curve for the eutectic brings out this point well.

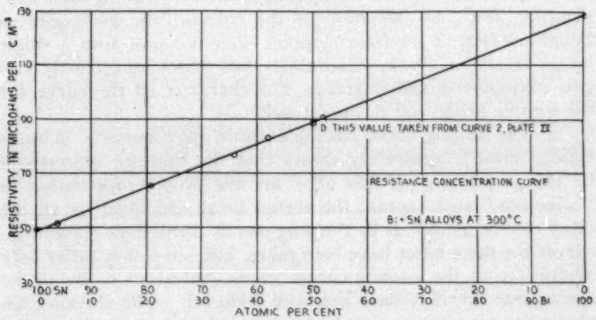
2. The heating curve for the eutectic alloy, curve 2, is interesting, since it apparently shows that the mixture represented by the proportions of this alloy are the proper proportions to "wipe out," so to speak, the abrupt break exhibited by all the other curves, as well as by the pure metals themselves. Heating-curves for these latter have been taken, but, since they differ only slightly from the cooling-curves given and seem to be of no special interest, they have not been included. The phenomenon above mentioned, associated as it is with the alloy having the lowest freezing-temperature, rather suggests some sort of a definite relation existing between the molecular condition or arrangement which causes a lowering of the freezing-point of the alloy and the molecular condition or arrangement functioning to change the resistance of the alloy.

3. When consideration is taken of the fact that the liquid phase of a metal or alloy possesses no crystalline structure, at least in the case here referred to, and is homogeneous throughout, it is logical to conclude that a systematic study of the electrical resistivity of various metals and alloys in their liquid phases might yield some very interesting and important information and furnish thereby a new basis for the comparison of this property with other properties of the metals or alloys. In this connection the curve, Plate V, is of unusual interest. This curve shows that a linear relation exists between the resistivity of the various alloys of bismuth and tin and the percentage of gramme-atoms of each constituent forming the alloy. Whether such a relation or some

other simple relation holds true for alloys of other metals is, of course, a matter of more or less speculation.

To obtain a more specific relation between the resistivity, concentration, and temperature of the alloy Bi-Sn, we can proceed as follows: Let R = resistivity of an alloy of Bi and Sn at concentration c and temperature t, where c is a quantity varying from zero to unity, being unity when the alloy consists of, say, 100 per

PLATE V.



cent. tin and zero per cent. bismuth—per cent. to be reckoned as above described. The temperature will be reckoned in degrees Centigrade. Then assuming $R = f(ct)$,

$$dR = \frac{\delta R}{\delta c}dc + \frac{\delta R}{\delta t}dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

But on the assumption that all the resistivity-temperature curves have approximately the same slope, we may write

$$\frac{\delta R}{\delta t} = m.$$

Again, considering Equation (7) as a total differential,

$$\frac{\delta}{\delta t}\left(\frac{\delta R}{\delta c}\right)_t = \frac{\delta}{\delta c}\left(\frac{\delta R}{\delta t}\right)_c \text{ or } \frac{\delta}{\delta t}\left(\frac{\delta R}{\delta c}\right)_t = \frac{\delta}{\delta c}\left(\frac{\delta R}{\delta t}\right)_c = \frac{\delta}{\delta c}(m) = 0.$$

Here $\frac{\delta R}{\delta c} = K$ where K is a constant (see curve, Plate V). Equation (7) now can be written $dR = Kdc + mdt$, which upon

integration gives, $R = Kc + mt + p$, where p is the constant of integration.

To evaluate p, let $t = O$ and $c = O$, then $p = R_o^{Bi}$ where R_o^{Bi} is defined as the intercept of the linear portion of the resistivity-temperature curve for pure bismuth projected back to cut the R axis.

Finally then,

$$R = Kc + mt + R_o^{Bi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

The constant K and m in Equation (8) must, of course, be obtained from the slopes of the resistivity-concentration curve and the resistivity-temperature curves, respectively.

The resistance-temperature coefficients of the alloys in the liquid phase can, of course, also be expressed in terms of the concentration c and the temperature t. While this gives no new information, it is interesting to find an expression for it. Calling this coefficient α defined as $\frac{1}{R_o}\frac{dR}{dt}$, we obtain from Equation (8)

$$\alpha = \frac{1}{R_o}\frac{dR}{dt} = \frac{K\frac{dc}{dt} + m}{Kc + R_o^{Bi}}.$$

Since c and t are independent variables, $\frac{dc}{dt} = O$, whence

$$\alpha = \frac{m}{Kc + R_o^{Bi}} \quad \text{or}$$

$$K\alpha c + \alpha R_o^{Bi} = m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Equation (9) is obviously the equation of an hyperbola.

Referring again to Curve 2, Plate IV, it will be noticed that the resistivity of this alloy of Bi and Sn (50 per cent. Bi and 50 per cent. Sn, each being in per cent. of gramme-atoms of each constituent) at 300° C. checks exactly with the value taken from the curve, Plate V. When it is considered that the data for the former were taken with apparatus differing quite essentially from that used in the case of the latter, the agreement is indeed gratifying and illustrates fully the practical value of the methods herein described.

PALMER PHYSICAL LABORATORY,
Princeton, N. J.,
May, 1916.

Brick Chimney Strengthened by Reinforced Concrete. E. McCULLOUGH. (*Engineering Record*, vol. 74, No. 6, August 5, 1916.)—Repairs to a dangerously cracked brick factory chimney 150 feet high successfully transformed it, to all external appearances, into a concrete chimney. A reinforced concrete shell was built around the old brickwork, using the latter as interior and galvanized steel as exterior forms, without interrupting the operation of the plant. The total cost of the work was about one-half the original cost of the brick chimney. This chimney was built 14 years ago. Three years after it was erected cracks appeared without any apparent reason, which gradually increased in size until last year when they excited alarm, and threatened to cause the cancellation of insurance policies on adjacent structures.

A concrete casing 10 inches thick was placed around the square base, 37 feet in height, above the base on the tapered shaft; the concrete is 8 inches thick at the bottom and 6 inches thick at the top. The horizontal reinforcing bands consist of ½-inch bars spaced 24 inches apart. The total cost of the concrete work was $2465, and the original cost of the chimney from the ground line to the top, $4800.

Using Steam Heat for Melting the Softer Metals. R. CRAMER. (*American Machinist*, vol. 45, No. 5, August 3, 1916.)—In its manufacturing process the Amalgamated Machinery Corporation of Chicago uses large quantities of type metal, an alloy of lead and antimony, for setting bearings and the like in cored castings. The alloy has a melting-point of 475° F., and it is essential that it be poured at a temperature not exceeding 550° F. Ordinary gas-heating melting furnaces such as are in common use for this kind of work necessitate the constant vigilance of an attendant using a thermometer in order to prevent overheating of the metal bath.

It was thought that by means of a coil containing steam at sufficiently high pressure, the latter being kept constant automatically, the metal bath could be kept in proper condition, ready to be drawn from without an attendant. The pressure at which saturated steam has a temperature of 550° F., is 1050 pounds per square inch. It was found, however, that to insure transfer of heat, desirable to employ a temperature of 600° F., corresponding to a pressure of 1575 pounds per square inch. An apparatus designed by Winslow Brothers, of Chicago, consisting of a receptacle carrying a steam coil for heating a cast-iron crucible connected to a high-pressure boiler of special design, heated by gas, fulfilled the requirements. The details of the apparatus have worked reliably in practical operation, and it is possible to keep the metal in a melted condition at the desired temperature, ready for instant use, without more attention than a casual glance at the pressure gauge.

A CENTURY OF LIGHT.*

BY

WALTON CLARK, M.E., D.Sc.,

President of The Franklin Institute.

MR. PAUL, the chairman of the Committee on Instruction of The Franklin Institute, has conferred upon me the honor of addressing you to-night. Since Mr. Paul has left the subject of my talk to my selection, I, as might be expected from my profession in life, have elected to speak of light, and "A Century of Light" is the subject of my story—the wonderful growth in the volume of artificial illumination in the century beginning with the year 1815, the date upon which artificial illumination began its career as a public service industry.

The lighting industry, as a public service, is all of the hundred years just ended; mainly of its latter half. In the earlier decades of the century, adventurous men spent their lives amid the perils of the Arctic, slaughtering harmless mammals, and bees were robbed and domestic animals gave their lives, that with train oil lamps and moulded tapers man might mitigate the evening's gloom. And then came gas lighting as a public service industry. The longest step in the advance of artificial illumination, from the building of the first fire to this hour, was taken when a material capable of yielding light upon combustion, requiring no storage upon the premises of the user, always ready for use, and measured as used, was made available to man. We may not deny that this long step in the art of artificial illumination was among the first of the gigantic strides with which material civilization has marched through the century.

The art of illumination by manufactured gas had its birth prior to 1815, but it did not attain the dignity of a public service industry until 1815. Nor were the discoveries made prior to 1815 of great importance, except that they demonstrated the practicability of the general distribution of what Bonaparte called "Une Grande Folie," and Walter Scott referred to as the project of a "madman," and later as a "pestilential innovation." In 1796, Philadelphia—always prominent in matters relating to the gas industry, and, except for its disastrous experiment with munic-

* Address to the Graduating Class of the Franklin Institute School of Mechanic Arts, April 14, 1916.

ipal ownership, always with an enviable prominence—had a sight of the "Folie," and it was the first sight of the wonder had in the United States.

Watson, in his Annals of Philadelphia, tells us that "The first gas made in Philadelphia, or in the United States, was manufactured by M. Ambroise and Company, Italian fireworkers and artists, and was exhibited in burning lights of fanciful figures . . . , at their amphitheatre, Arch Street, between Eighth and Ninth, in August, 1796."

The earliest recorded attempt to provide a gas works for an American city was made by Dr. Bollman, in Philadelphia, in the first year of our century, 1815. In Philadelphia we are frequently the first to start, but sometimes we are slow on the road. Philadelphia had the first start towards the first American gas works, but Baltimore and New York had gas works before Philadelphia. And the enterprise of the Italian citizens of Philadelphia, and of Dr. Bollman—indicative each of a progressive spirit in our city—is in contrast to a protest of many prominent citizens, addressed to the Select and Common Councils, and entitled "A Remonstrance Against Lighting With Gas." This protest, which was registered in 1833, arraigned gas as a powerful and destructive agent, and the consequences of its use are called "appalling." It concludes: "In conclusion, we earnestly solicit that the lighting of our city with oil may be continued." Among the several hundred signers of this protest are many names well known to-day in Philadelphia business, social, and professional life. But the prominent gentlemen failed of their purpose, and two years later, after Mr. S. V. Merrick had studied gas lighting in Europe, and recommended it to the citizens and government of Philadelphia, Philadelphia established a gas works, with Mr. John C. Cresson as engineer. Mr. Merrick was one of the founders of The Franklin Institute, and for twelve years its president. Mr. Cresson, the builder of the first gas works in Phildelphia, was at that time one of the managers of The Franklin Institute, and later, for eight years, its president.

From the beginning of history to the beginning of our century of light there had been no radical advance in the art of nocturnal illumination. Tapers and lamps consuming oil through a wick were used when the Pyramids of Egypt were built; and tapers and

lamps using oil through a wick were—aside from what we call fires—the sole source of artificial illumination at the beginning of our century of light.

And during the first four decades of our century sperm oil and candles were practically the only illuminants used by the average city-dwelling family of moderate means. Gas was not generally to be had, and, where it might be had, was too costly for the average purse, though it was proving its value to those who could afford it, and was coming into favor as a street illuminant. During these forty years, from 1815 to 1855, there was no material increase in the amount of lighting in the homes of people of small means—the great mass of the population. Whale oil throughout these four decades sold at about 80 cents per gallon, except that from 1845 to 1855 the average price was $1.77 per gallon. This high price was due to the increasing scarcity of whales. The high price of whale oil resulted in so greatly reduced profits that ship-owners gave up the whaling business. The supply was proving far short of the demand, though the demand must have been greatly reduced by the advance in the price. Fortunately for the purse of the householder, a new lamp oil came into use at about this time, when the discovery of petroleum in Pennsylvania gave kerosene to the world, and life to the few remaining whales.

During these four decades, 1815 to 1855, tallow candles sold at approximately 15 cents per pound. There were six candles to the pound, and each candle cost 2½ cents and had a life of seven burning hours. A candle cost, therefore, about one-third of a cent per hour burned.

Light, in this country, is expressed in candle-power. Candles vary in the amount of light they give, but not greatly when under similar atmospheric conditions. The standard of illumination in England and America is the light given by a so-called sperm candle, of prescribed composition and wick, and burning at the rate of 120 grains per hour, in an atmosphere so quiet that the flame does not flutter and the sperm does not gutter. And a candle-power hour is this amount of illumination maintained for one hour. Under such conditions a wax candle will give almost exactly the same amount of light as a sperm candle—the wax candle burning approximately ten per cent. less weight of material

TABLE I.

Showing the Estimated Amount and Cost of Illumination for Family of Five (5) Persons of Average Means at Different Periods of the Century Just Ending.

Period	Character of illuminary	Unit cost of energy	Number and kind of lights	Hours per night for one unit	Total candle power hours per year	Total cost of energy	Maintenance		Total cost energy and maintenance	Total cost per 1000 candles
							Material per year	Cost		
1815 to 1855	Sperm oil	$1.054 per gal.	2 sperm oil lamps (each 7.5 c.p. 2 oz. oil per hr.) = 3 hrs. per night for one lamp; and	3	8212.5	$19.75	——	——	$21.95	$2.50
	Candles	0.161 per lb.	5 tallow candles (6 to the lb. each 175 grs. per hr.) = 1¾ hrs. per night for one candle.	1¾	547.5	2.20	——	——		
1855 to 1865	Kerosene	.80 per gal.	2 camphene lamps (each 8.1 c.p. 1″ wick 1.75 oz. per. hr.) = 4 hrs. per night for one lamp; and	4	11826.0	19.50	——	——	23.25	1.88
	Candles	.274 per lb.	5 tallow candles = 1¾ hrs. per night for one candle.	1¾	547.5	3.75	——	——		
1865 to 1875	Kerosene	.55 per gal.	2 kerosene lamps (each 10.7 c.p. 1.5 oz. per hr.) = 5 hrs. per night for one lamp; and	5	19527.5	14.30	——	——	17.72	0.884
	Candles	0.25 per lb.	5 tallow candles = 1¾ hrs. per night for one candle, *or*	1¾	547.5	3.42	——	——		
	Gas	2.50 per 1000 c.f.	2 open-flame gas burners (each 14 c.p. 5 cu. ft. per hr.) = 5 hrs. per night for one burner; and	5	25550	22.80	——	——	34.21	0.894
			5 gas burners = 2½ hrs. per night for one burner.	2½	12775	11.41	——	——		
1875 to 1885	Kerosene	.22 per gal.	1 round-wick kerosene lamp (38 c.p. 4.5 oz. per hr.) = 3 hrs. per night; and	3	41610	10.29	——	——	30.36	0.401
	Gas	2.00 per 1000 c.f.	1 open-flame gas burner (17 c.p. 5 cu. ft. per hr.) = 2 hrs. per night; and	2	12410	7.30	——	——		
			5 gas burners = 3½ hrs. per night for one burner.	3½	21717.5	12.77	——	——		
1885 to 1895	Kerosene	1.35 per gal.	1 round-wick kerosene lamp (38 c.p. 4.5 oz. per hr.) = 3 hrs. per night; and	3	41610	6.32	——	——	25.49	0.283
	Gas	1.50 per 1000 c.f.	3 open-flame gas burners (19 c.p. 5 cu. ft. per hr.) = 2 hrs. per night; and	2	13870	5.47	——	——		
			5 open-flame gas burners = 5 hrs. per night.	5	34675	13.70	——	——		

1895 to 1905	Gas	1.00 per 1000 c.f.	2 incandescent gas lamps (each 70 c.p. 4.5 cu. ft. per hr.) =6 hrs. per night for one lamp; and	6	153300	9.85	2 incandescent mantles at $.35	$ .70	19.68	0.101
			5 open-flame gas burners (each 22 c.p. 5 cu. ft. per hr.) =5 hrs. per night for one burner, *or*	5	40150	9.13	———	———		
	Electricity	0.10 per kwh.	2 carbon incandescent electric lamps (each 14 c.p. 64 watts) = 6 hrs. per night for one lamp; and	6	30660	14.02	8 bulbs at $.20	1.60	24.97	0.488
			5 electric lamps =4 hrs. per night for one lamp.	4	20440	9.35				
1905 to 1915	Gas	1.00 per 1000 c.f.	Small income family, 1 incandescent gas lamp (70 c.p. 4.5 cu. ft. per hr.) =3 hrs. per night; and	3	76650	4.93				
			1 incandescent gas lamp (55 c.p. 3.5 cu. ft. per hr.) =2 hrs. per night; and	2	40150	2.56	7 incandescent mantles at $.15	1.05	12.19	0.073
			5 incandescent gas lamps (each 35 c.p. 2.5 cu. ft. per hr.) =4 hrs. per night for one lamp.	4	51100	3.65				
			Larger income family, 2 incandescent gas lamps (70 c.p. 4.5 cu. ft. per hr.) =6 hrs. per night for one lamp; and	6	153300	9.85	9 incandescent mantles at $.15	1.35	16.68	0.069
			7 incandescent gas lamps (40 c.p. 2.5 cu. ft. per hr.) =6 hrs. per night for one lamp.	6	87600	5.48				
1905 to 1910	Electricity	0.10 per kwh.	2 metallized filament electric lamps (each 18 c.p. 50 watts) = 6 hrs. per night for one lamp; and	6	39420	10.94				
			5 electric lamps =4 hrs. per night for one lamp.	4	26280	7.30	8 bulbs at $.20	1.60	19.84	0.302
1910 to 1915	Electricity	0.10 per kwh.	Small income family, 2 tungsten electric lamps (each 32 c.p. 40 watts) =5 hrs. per night for one lamp; and	5	58400	7.30				
			5 electric lamps =4 hrs. per night for one lamp.	4	46720	5.84	4 bulbs at $.50	2.00	15.14	0.144
			Larger income family, 2 tungsten electric lamps (each 32 c.p. 40 watts) =6 hrs. per night for one lamp; and	6	70080	8.77				
			7 electric lamps =6 hrs. per night for one lamp.	6	70080	8.77	4 bulbs at $.50	2.00	19.54	0.139
1	2	3	4	5	6	7	8	9	10	11

per hour. A tallow candle will burn forty-six per cent. more material than the sperm candle, and will give almost exactly the same amount of light. The tallow candle, once an important article of commerce, has practically disappeared. I believe you cannot find one on sale in Philadelphia to-day.

The conditions under which candles are ordinarily burned—being living-room conditions—cause the candles to give less light than when in a more quiet atmosphere. It is probable that the average illumination obtained from a candle in ordinary use is not greater than one-half of a so-called candle-power. But in the figures that I am now discussing, except as otherwise stated, I credit the candle with giving the amount of light that is given by a standard candle burning 120 grains per hour in a quiet and pure atmosphere.

The illuminating power of the electric light is not affected by atmospheric conditions. The illuminating power of the Welsbach burner is little affected by atmospheric conditions, except that a strong and intermittent draft will reduce its value somewhat.

I will now have put upon the screen a table presenting graphically the data that follow in the text, that you may more readily comprehend my story.

During these four decades, 1815 to 1855, the householder of average means, in American cities, had light in his home equivalent to approximately nine thousand candle-hours per annum; and the cost per family, these first forty years of our century, was approximately $22 per annum. Unless our grandfathers were better circumstanced that the average householder of their day, they paid probably $22 per year for their nocturnal illumination, and they enjoyed the equivalent of about twenty-five candle-hours lighting per night. This takes account of the expenditures made directly for illumination, and of the illumination provided by such expenditure. To this amount of light should be added whatever of the energy developed by fires maintained for heating and for cooking was utilized for illumination. In that early day and among people of small means a considerable amount of the evening work of the household and of the study of the children was done by firelight.

The decade 1855 to 1865 saw the introduction of the kerosene

lamp into the homes of people of average means. This resulted at once, in an increase of nearly fifty per cent. in the amount of illumination, without material change in its cost. Sperm-oil lamps, burning two ounces of oil per hour, average approximately 7.5 candle-light. The camphene lamp of that day, burning kerosene oil, consumed 1¾ ounces of oil per hour, and gave approximately 8 candle-power. The oil cost was approximately the average cost of sperm oil through the greater part of the preceding four decades—80 cents per gallon. There was one marked advantage in the use of the kerosene over sperm oil—the wick kept much freer from carbon, requiring much less frequent snuffing. This snuffing was a serious nuisance to the users of whale-oil lamps. The serious disadvantages in the use of the kerosene of that early period were the frequency of the explosion of the coal-oil lamps and the smell of the lamps. These were due to the presence in the kerosene of other and more volatile hydrocarbon products of the distillation of petroleum. With greater knowledge, and greater care in the fractionating of petroleum, has come a quality of burning fluid, or kerosene, that makes the kerosene lamp practically as safe as a candle, and as odorless.

The light of twenty standard candles was probably nearly the maximum amount of light in the household of people of average means during the lighting hours of these five decades—the first half of our century; and the total lighting in such a household was about nine thousand candle-hours per year. The amount of light now being thrown into this room for its illumination is about 2500 candles. The lamps now burning in this room would give in four hours as much light as our forebears—if of average financial position—used in their houses in a year of nights.

The decade from 1865 to 1875 witnessed a very material improvement in the character of the kerosene lamp and a material reduction in the price of kerosene. During these years kerosene could be purchased at 55 cents per gallon, and 1.50 ounces of the oil would maintain 10.7 candle-power light for an hour.

This—1865 to 1875—is the last decade of the tallow candle as an important factor in the domestic economy of a city-living people of average means. It is also the period in which gas became an important factor in the lighting problem of city people. The candle-hours per annum of illumination averaged 20,000 to 38,000—about three times the lighting during the first five decades

of our century. The cost per family using kerosene and candles was slightly reduced, and the cost per family beginning to use gas was increased from approximately $23 to $34. Gas, during that period, sold at about $2.50 per thousand cubic feet. The maximum amount of light in the household, during the lighting hours of that decade, was about 100 candles—one twenty-fifth of the amount of light in this room at present.

From 1875 to 1885, and thereafter, the use of candles for illumination by city families of moderate means was a negligible quantity. Kerosene had been reduced to 22 cents per gallon, gas to $2 per thousand cubic feet. At these lower rates artificial illumination had been so cheapened, and coincidently the means of families of average means had so increased, that the amount of illumination per annum rose 300 per cent. to 76,000 candle-hours, and the cost rose about seventy per cent. to approximately $30 per year. The maximum light in the household during this decade was 140 candles, or about one-eighteenth of the light in this room.

From 1885 to 1895 kerosene dropped to 13½ cents per gallon, and gas to $1.50 per thousand cubic feet. The greatest improvement in lighting devices ever covered in one step was given the gas consumer at this time—1885—in the Welsbach lamp. This invention of Auer von Welsbach at once increased the light-yielding efficiency of coal-gas from three candles to twenty candles per cubic foot. By this time kerosene and the kerosene lamp had been given a circular wick, and so improved otherwise as to give 38 candle-power, with a consumption of 4.5 ounces of kerosene per hour. The cost of illumination, whether with gas or kerosene, in this period—1885 to 1895—was approximately $25 per annum for the average family.

From this time—1895—kerosene practically disappears from the domestic economy of families of average means in the city of Philadelphia, and gas and electricity take its place; gas at $1 per thousand cubic feet, and electricity at about 10 cents per kilowatt —the gas used in Welsbach burners, and the electrical energy consumed in incandescent carbon filament lamps of 16 candle-power. Families of average means, using gas, from 1895 to 1905, had an illumination of approximately 200,000 candle-hours per year, and at a cost of approximately $20 per annum. Families using elec-

tricity during this period had approximately 51,000 candle-power hours per year for illumination, at a cost of approximately $25.

During the last decade of our century there has been a notable improvement in Welsbach incandescent gas lamps and a more marked improvement in electric incandescent filament lamps. The efficiencies of the latter have been twice influenced—once by the introduction of an improved carbon filament, and again, and more profoundly, by the introduction of the tungsten filament. I am referring now to lamps for domestic use. There has been a further very marked improvement in the economy of electric illumination of large spaces through the use of the flaming filament arc and nitrogen-filled incandescent lamps. The tungsten filament vacuum lamp is used almost exclusively, where electricity is used, for domestic purposes, and it is the lamp that is now lighting this room.

In the last year of our century, thrifty families of five people—city residents—and of average financial strength will use for lighting, if with gas, approximately 200,000 candle-power hours per year, at a cost of approximately $14.50 per year; and a similar family, using electricity for illumination, will probably use 123,000 candle-power hours per year, at a cost of approximately $17.50 per year. The maximum light in the average household is now approximately 360 candles—about one seventh of that in this room, and eighteen times the light of a similar household in the earlier decades of our century.

These somewhat tiresome figures show that coincident with an increase of 1700 per cent. in the amount of night lighting, not including firelight, of an American city family, in average circumstances, using gas for light, there has come a reduction in the cost of the year's lighting of 34 per cent., or approximately $7.50 per year; and that the cost of lighting per unit of light—the candle-hour—is now but two and eight-tenths per cent. of what it was in the first half of our century. No other necessity of household use has been so cheapened and improved during the century.

The figures that I have just given you are my estimate of the amount and of the cost of the nocturnal illumination enjoyed in the households of people of average means, dwelling in Philadelphia. They are based in part on the memory of elderly people. They are probably very nearly correct.

If The Franklin Institute were paying current rates for small

consumers—10 cents per kilowatt—for the electric current used in the tungsten lamps, the light in this room would be costing the Institute approximately 25 cents per hour of illumination.

At the beginning of our century of light there was nowhere in the world such brilliant and inexpensive lighting as we have in this room, though there was much more beautiful lighting than that of this room, good as it is.

Washington's Birthday was celebrated in 1817 with a great ball in Washington Hall, on South Third Street, five hundred people being present. The chronicles report the room as being lighted by two thousand wax candles—giving probably a thousand candle-power. It is referred to as an instance of room lighting of great brilliance, and it must have been very beautiful. It was brilliant and costly lighting for that period, and, in my opinion, sufficiently brilliant for a ball-room of any period. If the ball continued (as I am told was the custom during the administration of President Madison) from 9 P.M. to 2 A.M., the cost of the lighting was about $150, equal to $30 per hour—two-fifths the amount of light in this room, and at one hundred and thirty-six times the cost.

The old Shot Tower, still standing near the old Gloria Dei Church, was that night illuminated with one hundred and sixty lamps. A chronicle of the day calls it a "veritable tower of light." At the best the total amount of light used in its illumination was about one thousand candles—the equivalent of about one arc electric lamp. The cost for oil used to produce this illumination was probably about $2.40 per hour of lighting.

To furnish a comparison with the above figures, I instance the lighting of this room, equalling about 2500 candles, and costing 25 cents per hour and 10 cents per 1000 candle-hours; the present lighting of the foyer of the Academy of Music, with Welsbach incandescent lamps, having a total lighting power of 3800 candles, and costing 28 cents per hour and 7 cents per 1000 candle-hours; and the lighting of the front of the office of The United Gas Improvement Company, at Broad and Arch Streets—the lamps there used being known as high-pressure, incandescent gas lamps—having a total lighting value of 16,000 candle-power, and costing 53 cents per hour and 3.3 cents per 1000 candle-hours. I cite these instances of modern illumination not with pride, nor necessarily with approval, but as evidence that the development

of the business in which I have been engaged—the public service lighting business—and the cheapening of artificial light—easily has outpaced the development of any other industry or science known at the date of its birth an hundred years ago.

TABLE II.

Showing the Estimated Amount and Cost of Street Lighting in Philadelphia at Different Periods of the Century Just Ending.

Year	Number of street and public lamps	Population	Total yearly cost of lighting to city, taking the free gas lamps as if at current prices	Approximate candle power		Approximate cost per 1,000 candle hours	Description of large units
				Total	Per capita		
1	2	3	4	5	6	7	8
						Cents	
1809	Whale oil, 1,132	58,000	$19,263.75	8,490	0.15	56.72	Sperm oil wick lamps
1850	Gas, 1,966	121,000	$43,252.00	35,388	0.29	30.56	18 C. P. gas Argand burner
1885	Gas, 14,268 Naphtha, 3,360 Electric, 198	950,000	$420,577.05	491,876	0.52	21.38	17.3 C. P. gas flat flame 14 C. P. Maloney burner Open D. C. arcs, 9.6 amperes, 47 volts
1915	Gas, 24,300 Naphtha, 19,987 Electric, 14,635	1,765,810	$2,392,935.90	17,241,359	9.76	3.47	Welsbach burners gas Welsbach burners naphtha Open D. C. arcs, 9.6 amperes

We have in this table a graphic presentation of the amount and growth, and cheapening of the street lighting of Philadelphia during the century just past.

The growth in population from 1809 to 1915 was approximately from 60.000 to 1,750,000, or nearly 3000 per cent. The increase in the amount of street lighting was approximately 200,000 per cent. The decrease in cost of street lighting per unit of light was approximately 95 per cent. The increase in the amount of light per capita of population was 6400 per cent., and the increase in cost per capita was 308 per cent. The gas lamps, for which the city does not make a cash payment, are included in these figures at current rates.

The suggestion of brighter nocturnal illumination in the streets of cities and in the houses of the well-to-do, carries nothing of inspiration to any man. There can be little joy in adding to

what already is, at least, enough. But the suggestion of a possible further reduction in the cost of nocturnal illumination—a reduction that shall mean a reasonable amount of lighting in homes now, through poverty, dark; rendering safer, more beautiful, and more cheerful the surroundings of the poor—carries much of inspiration to the engineers of the lighting fraternity. And there is promise of such reduction, cheap as artificial illumination now is—cheapened as it has been through decades that have witnessed a cheapening in little else. Small room as there is for a further reduction in the cost of gas and electricity, there is prospect of a cheapening of light through improvement in gas and electric lamps.

TABLE III.

Total Luminous Efficiencies of Light Sources.

Source	Efficiency, per cent.	
Sperm candle.....	.02	
Flat flame gas.....	.036	
Incandescent mantle gas.....	.190	
Carbon filament electric.....	.420	
Tungsten filament electric.....	1.3	
Firefly.....	*86.4	

* Assuming the efficiency of the firefly as a transformer of bodily energy into radiation is 90 per cent.

In the conversion of energy—actual and potential—through thermodynamic or chemical action—into light, there is a development of heat, necessary to the process, but greatly out of proportion to the lighting result obtained.

The whale-oil lamp converted to light one five-thousandth

part of the energy stored in the oil. The standard sperm candle also converts to light one five-thousandth part of the energy developed in its combustion. The most efficient artificial lighting unit known at the present time is the yellow flame electric arc light, and this delivers as light but one-fifteenth of the energy of the electric current producing it, and but one one-hundredth of the energy in the coal which is the ultimate source of electric energy. The lamps lighting this room convert to light but thirteen one-thousandths of the energy of the current supplied to them. The Welsbach domestic gas-lamp yields as light two one-thousandths of the energy in the gas burned in it. In these modern lighting units, the most efficient yielding to our useful purposes but seven per cent. of the energy delivered to it, and the least efficient—to my eye the most beautiful—yielding but two-tenths of one per cent. of the energy delivered to it—it is evident there is an opportunity for further economies, greater, perhaps, than those offering in any other field of industry. The brains and hearts of men of the highest scientific attainment are devoted to this opportunity—not of making brighter the places already bright, but of so cheapening artificial light that they who, through poverty, now sit in nocturnal darkness may have light; and that what light is had, and by whatever class had, may be so applied to use as to simplify the lives and beautify the surroundings of the users. The possibilities of improvement are somewhat indicated by the fact that the lamp of the fire-fly has an efficiency of 86 per cent.—twelve times greater than the most economical of our sources of artificial light.

Young men, I deem it my duty, in this day of conflict, of unrestrained national passion—though I stand in the Quaker City, and in the hall of an institution for whose existence Quakers are largely responsible—to speak to you a few words of the condition of our nation and of what, in a military way, our nation may reasonably expect from us in its day of danger.

Each of the certificates that will be given to you to-day bears three wood-cuts. Two of them are indicative of what the charter of The Franklin Institute declares to be its function—the promotion of the mechanic arts. The third wood-cut is a figure of Liberty leaning on the shield of our country. This figure and shield indicate the expectation of the founders of our institution that the young men who graduate from our school will have an

interest beyond that concerning their immediate means of livelihood; an interest in the safety, honor, and welfare of the American Republic, and in its means of defense.

You, young men, workers in the industries by day, have given evidence, by your work in our schools at night, of a discipline and self-denying spirit that are a gratification and inspiration to those who know of it. It is to men of this discipline and of this spirit, wherever and however had, that our nation must look for help in its present time of need. You, by reason of the evidence you have given of this discipline and this spirit, are marked men among your associates. Accustomed to looking toward the future and working for a future good, your kind, of all men, should be the first, after the soldier and sailor defenders of our flag, to foresee a peril and to sound the alarm. After the soldiers and sailors, your kind should be found most nearly ready and conditioned to do a part in the defense of the nation.

I think we must believe that our government will finally adopt a policy of preparedness for war that will insure the future peace of the nation. This certainly will be if our lawmakers are convinced that their constituents demand it. As far as we can, let us help them to this conviction.

And, however this may be, let us highly resolve that whatever our nation, as a nation, may do; however adequate or inadequate may be the measures it takes to protect our homes and our liberties, our country will find *us*, in its time of need, ready, at its call, to stand with our lives and our fortunes "between our loved homes and the war's desolation." And, my friends, let each man of us further resolve so to live that the service and the life he will have to offer his country in her hour of trial shall be as useful to her as, in God's providence, he is able to make them.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE FREEZING POINT OF MERCURY.[1]

By R. M. Wilhelm.

THE temperature at which mercury freezes is of importance in thermometry. It marks the lower limit to which mercurial thermometers may be used, and its location at about −39° C. makes it of value as a fixed point of the temperature scale below 0° C. A paper by the Bureau of Standards and which is now in press gives the result and describes in detail the method used in making a redetermination of this constant. The temperature measurements were made by means of platinum resistance thermometers whose constants had been previously determined by calibration at 0°, 100°, and 444.6° (the boiling point of sulphur). All the evidence at present available indicates that the platinum resistance thermometer calibrated as above, defines temperatures in agreement with those given by the standard gas thermometer down to −40°. The value obtained at the Bureau, −38.87°, is in very good agreement with that found by Henning in 1913 at the Reichsanstalt, Germany, who also used platinum resistance thermometers and obtained −38.89°.

THE SACCHARIMETRIC NORMAL WEIGHT AND THE SPECIFIC ROTATION OF DEXTROSE.[2]

By Richard F. Jackson.

PURE dextrose was prepared from starch conversion products and from invert sugar solutions. After a preliminary purging had removed a great portion of the adhering impurities, the substance was dissolved to form a 60 per cent. solution in water and the crystals allowed to form slowly during continuous agitation. Two or three recrystallizations were sufficient to produce dextrose of high purity. A portion was subjected to a fractional crystallization and another portion precipitated by ethyl alcohol. The various purified samples showed essentially identical properties.

Dextrose crystallizes from water solution with one molecule of water of crystallization which it loses very readily at 60° C.

* Communicated by the Director.

[1] Scientific Paper No. 294.

[2] Scientific Paper No. 293.

The residual moisture was removed by heating in a vacuum at 60° – 80° C for several hours.

To prepare the solution for polarization approximately the quantity required was weighed and dried in a weighed volumetric flask and the solution made up to the graduation mark of the flask at 20.0° C. From the data obtained the densities of dextrose solutions were calculated and found to correspond to the formula:

$$D_{4}^{20^\circ} = 0.99840 + 0.003788\ p + 0.00001412\ p^2$$

where p is per cent. anhydrous dextrose by weight in vacuo. The formula is valid for values of p between 5 and 30.

The solution was allowed to stand over night at room temperature in order to destroy the mutarotation.

Twelve independent measurements were made to determine the weight of substance which, contained in 100 cc. of solution, would cause a rotation of 100° S on the scale of the quartz-wedge saccharimeter. If the latter is controlled by the conversion factors determined by Bates and Jackson,[1] namely 34.620° for $\lambda = 5892.5$ A or 40.690° for $\lambda = 5461$ A or by the rotation of 26.000 g. of pure sucrose in 100 cc. the normal weight of dextrose is 32.231 g. weighed in air with brass weights. If the saccharimeter is calibrated by the Herzefeld-Schönrock factor 34.657° which Bates and Jackson have shown to be in error, the normal weight of dextrose is 32.264 g.

For more dilute than normal solutions the rotations deviate from proportionality. It is therefore necessary to apply corrections to make the scale reading indicate the per cent. of substance. At 90° S the correction is +0.20; at 80°, +0.35; at 70°, +0.46; at 60°, +0.53; at 50°, +0.55; at 40°, +0.53; at 30°, +0.46; at 20°, +0.35; at 10°, +0.20.

The rotation of the normal solution (32.231 g.) for $\lambda = 5461$ A is 40.898°. Since the normal quartz plate rotates 40.690° it is evident that there is a considerable divergence between the rotary dispersion curves of dextrose and of quartz. Thus when the quartz-wedge saccharimeter is set for a photometric match the field is slightly heterochromatic and the degree of reproducibility of the setting is necessarily less than that of sucrose whose

[1] *J. Wash. Acad.*, vi, p. 25 (1916); Bull. Bur. Standards 13, p. 67 (1916).

dispersion curve coincides more closely to that of quartz. This difficulty is only overcome by an increased number of settings and by some preliminary experience on the part of the observer.

The specific rotation which is a function of the concentration of dextrose corresponds to the formula

$$\left[\alpha\right]^{20.0}_{5461A} = 62.032 + 0.04257c$$

where c is grams of anhydrous dextrose weighed in vacuo and contained in 100 cc. of solution

or

$$\left[\alpha\right]^{20}_{5461A} = 62.032 + 0.04220p + 0.0001897p^2$$

where p is per cent. dextrose by weight in vacuo.

Apparatus for Determining Hardness of Metals. Anon. (*The Mechanical Engineer* (Manchester), vol. 38, No. 967, August 4, 1916.)—A simple device for testing the hardness of metals has been designed by Messrs. Vickars, Ltd., and R. L. Smith. It consists essentially of a square steel bar of known hardness against one face of which a steel ball is held in contact by a clip attached to a yoke fitted to the other faces of the bar. The clip is elastic so that the ball and yoke can be snugly held at any point along the length of the bar. To obtain the approximate hardness of an article under examination, the apparatus is placed with the ball resting against the article, and the yoke is given a light blow with a hammer. If the resulting indentation on bar and article to be tested are alike, the hardness of the material is that of the standard bar. If, however, there is any appreciable difference in the two impressions, the operation is repeated with a harder or softer bar until equal impressions are obtained, the figures marked on the end of the bar then giving the hardness possessed by the article under examination. For each successive test the yoke is moved along the bar until the ball rests upon an unindented surface. A pointer formed on the spring clip is provided. This is brought in register with the inner edge of the last impression and determines the nearest position of the next impression without danger of overlapping. The chief utility of the device is in ascertaining whether the hardness of an article lies between the limits determined by that of two standardized test bars.

A New Light Matching Pyrometer. ANON. (*Scientific American*, vol. cxv, No. 7, August 12, 1916.)—By comparing the intensities of colored light, one of known value and the other of a value that is to be determined, a recently developed pyrometer makes possible the measuring of the temperature of a heated body either within or without a furnace. The new pyrometer, although sufficiently compact to be carried about in the pocket, duplicates the color of heated bodies and at the same time indicates the temperatures on a calibrated scale with an error limit of one to two per cent. In general contour the apparatus is cylindrical, about 2 inches in diameter by 8½ inches long.

In operation it is held in the hand, and the body whose temperature is to be measured is viewed through a peep-hole near the end. Upon pressing a button a small incandescent lamp, supplied with current from a battery carried in the case of the pyrometer, throws a beam of light which passes through a screen of varying transparency and impinges in an inclined mirror that is visible when looking through the peep-hole. While the light is turned on, the observer manipulates one or the other of two knurled knobs, causing a graduated screen to be moved from one roller to another, bringing a lighter or darker section over the lamp aperture. When the two colors seen through the peep-hole appear to match, a reading is taken with the light still on. The numbers representing the various temperatures form part of the graduated screen and hence appear on the mirror. The light intensities as viewed through the pyrometer appear as different shades of blue. This color has been chosen for the reason that it lends itself well to making exacting comparisons between various shades.

Non-recoil Guns for Aeroplanes. ANON. (*Machinery*, vol. 22, No. 12, August, 1916.)—The two factors that limit the power of the armament for aëroplanes are the force of the recoil and the weight of the weapon. In order to overcome these limitations, the non-recoil gun has been developed, and its tests have thoroughly demonstrated that, regardless of calibre, there is practically no recoil force. The absence of recoil is due to the fact that, instead of having the gun closed at the breech end, it is left open by substituting a complete barrel for the usual breech-block, and firing through this barrel to the rear a charge of fine shot (equal in weight to the front projectile) that quickly scatters and loses its velocity. In this way the action and reaction are equal, so that there is no tendency for the gun to move in either direction. The powder charge is so arranged that it is all in one chamber, and ignition and combustion of the two charges are necessarily simultaneous. The elimination of the shock of the recoil makes it necessary to consider only the question of weight in limiting the size of an aëroplane gun. Many of these guns are now being built for foreign governments by the General Ordnance Company, Derby, Conn.

NOTES FROM NELA RESEARCH LABORATORY.*

THE REVERSAL OF A FADED NEGATIVE AFTER-IMAGE BY BRIGHTENING THE STIMULUS FIELD.

By Leonard T. Troland.

If the stimulus field upon which a negative after-image is projected is suddenly darkened, the luminosity contrast between the image and its surroundings is greatly enhanced. If, on the other hand, the field is brightened, the contrast is diminished, and, under the right conditions, will be *reversed*, so that the image becomes *positive*. The experiments described below were made to determine the influence of color and intensity upon this latter effect.

The after-image was produced by fixation of a semicircular field, 3 1/3 degrees in diameter, on a dark background, for 30 seconds, at the end of which time the full circle was exposed, fixation being maintained on the central point. Three seconds later the entire field was dimmed to one-tenth the primary intensity, and held at this value for 45 seconds, at the end of which time the original intensity was restored. At this instant the reversal appeared, if at all. When present, its duration was measured.

Eight spectral colors, at seven different intensities, were employed as stimuli. Six trials were made for each setting, and the results are shown in the following table. Under P is given the number of times a reversal was seen, under N the number of negative contrasts observed. T is the net average duration of the positive; *i. e.*, the sum of the duration of the positives minus the sum of the duration of the negatives, divided by the total number of cases. T is not calculated for the shorter wavelengths, on account of the small probability of significance of the values for these stimuli.

*Communicated by the Director.

INTENSITY IN PHOTONS.

Color and wave-length in μμ	6.40	16.00	40.00	100.0	250.0	625.0	1560
Red:							
676.4–700.0							
P	2	6	6	6	6		
N	3	0	0	0	0		
T	0.5	2.9	4.4	13.2	9.1		
Orange:							
614.4–631.0							
P	1	4	4	5	5	6	2
N	3	0	0	1	1	0	3
T	0.13	1.4	1.7	4.0	5.4	6.8	−1.3
Yellow:							
569.2–582.0							
P	1	0	2	1	3	5	6
N	2	3	2	2	2	1	0
T	0.0	−1.0	−0.5	−0.1	0.5	9.9	12.4
Yellow-Green:							
534.6–545.0							
P	1	0	0	1	5	6	6
N	1	1	3	1	1	0	0
T	0.0	−0.2	−0.4	0.2	3.1	5.9	5.5
Green:							
500.5–509.0							
P	0	3	2	1	2	1	1
N	0	2	1	1	1	1	0
T	0.0	0.2	0.8	0.2	0.3	−0.03	0.3
Blue-Green:							
485.4–493.0							
P	1	1	1	1	2	0	
N	0	1	1	1	0	0	
Blue:							
465.0–485.0							
P	3	3	2	0	1	1	0
N	1	1	1	1	1	1	0
Violet:							
424.0–436.7							
P	2	1	2	2	2		
N	2	0	2	1	1		

It will be observed that a distinct law governs the appearance of the phenomenon; it is present most strongly in the long-wave end of the spectrum, and with decrease in the wave-length higher and higher intensities are required to bring it out, so that in the short-wave end it is practically absent with the intensities here employed.

The writer acted as subject in the above experiment, the exposures being controlled by an automatic apparatus. The flicker photometer was employed for the establishment of intensities.

Nela Park, Cleveland, Ohio,
September 7, 1916.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

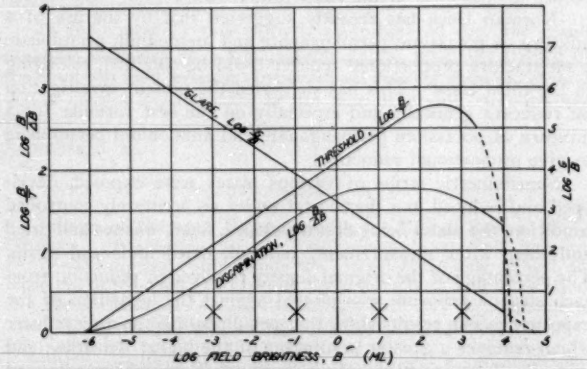
THE EFFECTS OF BRIGHTNESS ON VISION.

By Dr. P. G. Nutting.†

[*Abstract*]

THE eye adapts itself readily to a range of brightness from about 10^{-6} millilamberts (absolute threshold) up to about 50 lamberts, which is a little brighter than white paper in direct sunlight. This adaptation is in the nature of an automatically varying sensibility. Numerical data on this variation in sensibility have been obtained for the whole range of adaptation and are given below.

The three kinds of sensibility of more interest at any brightness level are (1) the lowest visible low light (2), the lowest perceptible contrast and (3) the highest tolerable highlight or Threshold, Discrimination and Glare Sensibility. Our data are given in the accompanying table and figure.


GLARE, LOG $\frac{B}{\Delta B}$
THRESHOLD, LOG $\frac{B}{\Delta B}$
DISCRIMINATION, LOG $\frac{B}{\Delta B}$
LOG $\frac{B}{\Delta B}$
LOG FIELD BRIGHTNESS, B (MIL)

* Communicated by the Director.

† Communication No. 38 from the Research Laboratory of the Eastman Kodak Company.

TABLE—VISUAL SENSITOMETRIC DATA.

Field Brightness	Different Fraction	Discrimination Factor	Threshold Limit	Glare Limit ml.
0.000001	(1.00)	1.0	0.00000093	20.1
0.00001	(0.66)	1.5	0.0000042	40.7
0.0001	0.395	2.5	0.000019	89.0
0.001	0.204	4.5	0.000087	186.0
0.01	0.078	12.8	0.00039	400.0
0.1	0.0370	27.0	0.00174	810.0
				I.
1.0	0.0208	48.2	0.0081	1.66
10.0	0.0174	57.5	0.036	3.47
100.0	0.0172	58.1	0.28	7.25
1,000.0	0.0240	41.7	2.15	14.45
10,000.0	(0.048)	(20.9)	(232.0)	30.90

ROCHESTER, N. Y.,
Sept. 21, 1916.

PROPORTIONAL REDUCERS.*

By Kenneth Huse and Adolph H. Nietz.

[*Abstract*]

Photographic reducing solutions may be divided into three classes: (1) those which attack the highest densities most, (2) those which attack the lowest densities most, and (3) those which reduce all densities in the same proportion.

Norman Deck has recently suggested that by the use of a mixture of potassium permanganate and ammonium persulphate a satisfactory proportional reducer could be obtained, belonging to the third class. This has suggested the present investigation on reducers generally and especially on the best formula for a mixture of potassium permanganate and ammonium persulphate to give proportional reduction.

Sensitometric strips of various plates were exposed, developed and reduced in a thermostat under an accurately controlled condition, the plates being first developed, fixed, washed and dried and then, after measurement, reduced, dried and read again. The percentage of the original density removed by reduction from each step of exposure was plotted against the logarithm of the exposure. The results show that persulphate is the only reducer which removes a greater percentage of the higher densities; and that all others tried, including some which have been supposed to work proportionally, really reduce the lower densities most,

* Communication No. 39 from the Research Laboratory of the Eastman Kodak Company.

so that they tend to remove the shadow detail, the reducer having the greatest influence in this direction being a solution of ferricyanide and thiosulphate, which reduces the shorter exposures to such an extent that its effect on the curve through the greater part of its action is exactly as though less exposure had been given to the plate, this reducer being very useful for correcting overexposure.

After a trial of various proportions of the permanganate and persulphate mixture suggested by N. Deck, the following formula was adopted as giving the most evenly proportional reduction:

Sol. A. Potass. Permanganate	0.25	gms.
10 per cent. sulphuric acid	15	cc.
Water	1000	cc.
Sol. B. Ammonium Persulphate	25	gms.
Water	1000	cc.

Use 1 part of A to 3 of B. The solutions will keep well and should not be mixed until ready for use. The time of reduction required will be from one to three minutes, depending on the amount desired. Reduction should be followed by immersion for five minutes in a one per cent. solution of potassium metabisulphite. The plate should then be washed for a short time.

In the course of this work it was observed that the result obtained depended to a considerable extent upon the nature of the emulsion used, even this proportional reducer showing greater action on the low densities in the case of a slow, fine-grained plate.

ROCHESTER, N. Y.,
SEPT. 19, 1916.

Sources of Nitrogen Compounds in the United States. C. G. GILBERT. (*Proceedings of the Smithsonian Institution,* June 30, 1916.)—Nitrogenous compounds are essential not only to self-defense but to the country's capacity for self-support, and to be effective the source must be such that the product may be adaptable to meet their requirement. The arc method of producing nitrogen compounds has not thus far demonstrated capacity to meet the agricultural requirement at all or even the defense requirement efficiently. Definite knowledge concerning the Haber process is lacking, but its record of achievement is against it, and it would seem, moreover, unsuited to American conditions, at least in the present

state of its development. The cyanamide process is capable of a development which will meet the requirements for a cheapened nitrogenous fertilizer source whose form of nitrogen content is readily convertible to nitric acid. The process is already a prominent factor in the economic well-being of most countries of older civilization, and is capable of similar extension in the United States.

By-product coking operations afford a source of nitrogenous compounds netting the country an annual production at the rate of over 200,000 tons of ammonium sulphate now, and due to raise this total to about 400,000 tons with the completion of the ovens now building. A total of about 700,000 tons would be possible if all coking were of by-product nature, and this total should be attained within the next few years. No practicable means for its oxidation to nitric acid have yet been found in this country. By-product ammonia constitutes the country's one actual asset in the form of nitrogenous compounds. It has a rapidly growing yield of very great importance in itself, but of even greater importance as a factor contributing largely to the commercial possibilities of a number of industrial lines, especially that of coal products. The country cannot afford to run any risk of checking development along these lines. The evolution of a practicable process for the oxidation of by-product ammonia to render present resources available, with the development of an atmospheric nitrogen fixation output by the cyanamide process carefully timed to meet growing demands following a reduction in the retail price of nitrogenous fertilizer, would appear to be the desirable governmental procedure as being the one least liable to disastrous consequences.

A Sensitive Magnetometer. P. E. SHAW and C. HAYES. (*Procedings of the Physical Society of London*, vol. xxviii, part v, August 15, 1916.)—A torsion balance of extreme delicacy carries a pair of purest silver balls, each 3 grains weight. A solenoid with horizontal axis passing through one of the silver balls is brought close to the balance. On exciting the solenoid, divergent fields of known strength are obtained in the region of the ball. The resulting attraction of the ball to the solenoid is shown by a mirror reflecting a distant scale to a telescope. The couple on the torsion beam required to produce 1 millimetre scale deflection is 4.5×10^{-7} dyne-centimeters, and this torsion balance is 10^6 times as sensitive as any known to have been used previously in this kind of work.

The results of these experiments are: (1) The magnetic properties of silver are ascertained even for weak fields of 1 to 10 gausses. (2) The silver has a pronounced retentivity, this effect being presumably due to the small trace of iron impurity. (3) The relation of susceptibility of the silver to the field used is found. The susceptibility of each of the constituent materials, pure silver and residual pure iron, appears to be greatly modified by the presence of other material.

NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

THE PLIOTRON OSCILLATOR FOR EXTREME FREQUENCIES.

By William C. White.[1]

The physical construction of the pliotron and its operation in various arrangements of circuits are described in detail with cuts. The connections for the production of frequencies as low as ½ cycle per second and as high as 50 million are shown by diagram and discussed. This latter frequency corresponds to a wave-length of 6 meters. The electrical conditions and methods for their measurement in such circuits are given.

THE LAW OF ABSORPTION OF X-RAYS AT HIGH FREQUENCIES.

By Albert W. Hull and Marion Rice.[2]

Measurements on "white" radiation from a tungsten target dispersed by a rock salt crystal, made by means of the ionization chamber, confirmed for copper and aluminum, the validity at even these short wave-lengths, of the law that the coefficient of absorption of metals varies approximately as the cube of the wave-lengths, except in the immediate vicinity of one of the wave-lengths characteristic of the metal. For lead the absorption of wave-lengths longer than 0.149 A. U. obeys the law, but below this wave-length excitation of the K fluorescent radiation begins.

Calculation of the "corrected absorption coefficient" or "transformation coefficient" shows that it is, for all substances and wave-lengths yet investigated, equal to a constant, peculiar to the substance, times the cube of the wave-length, over the entire range between absorption bands.

A table of the observed and calculated values for the mass absorption coefficients of aluminum, copper and lead at various wave-lengths from 0.392 to 0.122 A. U. is given.

* Communicated by the Director.

[1] General Electric Review, 19, 771-5, Sept., 1916.

[2] Physical Review, 8, 326-8 (Sept., 1916).

The "Kick" of the Gun. E. C. CROSSMAN. (*Infantry Journal*, vol. xiii, No. 1, July–August, 1916.)—Not the most pleasant part of shooting a military rifle is the vicious backward drive of the steel-shod butt against the muscles of the shoulder when the trigger is pressed. Experiments at the American School of Musketry at Monterey demonstrated that the limit of endurance under normal conditions lay at about three hundred rounds a day. From every standpoint—recoil, weight of ammunition, weight of rifle, and cost of ammunition—the smaller calibres than the present 0.30 of the American service are being proved desirable.

The "kick" of a rifle is purely a matter of the equal reaction of powder gases upon the bullet and the breech-closing mechanism. The final blast of the gases of the explosion against the comparatively solid body of air aids in the backward thrust of the rifle. In the American service, the formula for obtaining the backward speed of the rifle is as follows:

$$vW = Vw + 4700\ W^1$$

where v is the recoil velocity and V the muzzle velocity of the bullet in foot-seconds, and w the weight of the bullet, W^1 the weight of powder, and W the weight of the rifle, in grains. The American service rifle has a recoil velocity of 10.2 feet per second, which gives a recoil energy of 14.6 foot-pounds. While a grown man, husky and inured to hardships, is sensitive to the recoil of the service rifle, and while about three hundred rounds is the limit for a day's firing, strangely enough the recoil in foot-pounds of the 12-bore shotgun and the normal trapshooting cartridge is nearly double that of the rifle and is taken without a murmur by the thousands of trapshooters about the country. Evidently the position has most to do with the difference in the discomfort from the recoil of the two arms; the shotgun is fired with the muscles tensed and body moving—in other words, the shock is taken by the set of tensed springs; the rifle is fired with the muscles relaxed, fired deliberately. The shotgun has also a straighter stock, thus bringing the line of resistance nearer to the direction of recoil.

The noise of the military rifle, particularly the American 24-inch barrel Springfield, is very violent. The Maxim silencer has much effect in reducing the recoil, the theory being that the gases impinging on the disks of the cylinder actually drag up the rifle and help to resist the backward thrust of powder gases within the bore, as well as to eliminate the position of the recoil caused by the gases impinging on the resisting air at the muzzle. So the silencer works in two ways—in one by cutting down the weight of the thrust, in the other by relieving the nervous system of the shock from the report, which is actually painful to some ears. The fact that military authorities dislike to take up a rifle and cartridge giving more than 15 foot-pounds recoil energy, and the fact that lightening both rifle and ammunition is urgently needed, both go to show that the next change in our rifle should be toward a still smaller calibre than the 0.30—either the 0.25 or the 0.23.

NOTES FROM THE PHYSICAL LABORATORY OF THE UNITED GAS IMPROVEMENT COMPANY*

LIPPMANN FILMS AS MEANS FOR SECURING MONOCHROMATIC LIGHT IN PHOTOMETRY AND OPTICAL PYROMETRY.

By Herbert E. Ives.

SOME years ago the writer found that Lippmann color photographs of monochromatic light could be prepared in such a way as to make the light reflected from them of a high degree of purity[1] The special features of the procedure consisted in development with a developer which would act throughout the depth of the film and subsequent bleaching of the film by mercuric chloride.

The special Lippmann photographs reflect a portion of the spectrum so narrow as to appear like a line when examined by a small spectroscope. When the angle of observation is changed the wave-length of the reflected light shifts, moving further toward the blue the greater the angle.

The present work consists in the use of these sources of monochromatic light, first, as a means of carrying out Crova's method of color-difference photometry, second, as a substitute for the spectroscope or colored glass in the optical pyrometer.

In Crova's method of color-difference photometry the photometric field is observed by monochromatic light of a selected wave length for which the intensity of the two illuminants under comparison is as their total luminous intensity.[2] This wave-length varies slightly with the light sources measured, so that no single color screen or other device giving a fixed wave-length is entirely adequate. In using the Lippmann film for this purpose a special eye-piece carrying the film permits this to be rotated to the correct wave-length, thereby meeting the requirements for both monochromatic light and for a small range of variability of wave-length according to the illuminants compared.

For optical pyrometry the Lippmann film offers a simple substitute for colored glasses giving light as monochromatic as does the usual spectroscope as employed for this purpose.

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* Communicated by the chief Physicist.

[1] "An Experimental Study of the Lippmann Color Photograph," Ives, *Astrophysical Journal*, June, 1908, p. 325.

[2] "The Application of Crova's Method of Colored Light Photometry to Modern Incandescent Illuminants," Ives and Kingsbury. *Trans. Illum. Engr. Soc.*, November, 1915, p. 716.

THE LUMINOUS EFFICIENCY OF THE RADIATION OF THE ELECTRIC ARC.

By Enoch Karrer.

The work described in this paper is a completion of the work described in a previous paper on the luminous efficiency of the radiation of the ordinary light sources. (Physical Review, Vol. V, No. 3, March 1915, p. 189).

In the former the ordinary gas and electric light sources were studied. In the present work the electric arcs are the subject of study.

The luminous efficiency of the radiation is the fractional part of the total radiation that passes through an absorbing solution whose spectral transmission curve is identical with the luminosity curve of the eye.

Proper correction must be made for the absorption by the liquid of the radiation at the wave-length of maximum transmission.

Due to the fluctuations in the arc the method previously employed is not satisfactory.

By means of two thermopiles the total radiation and the radiation after passing through the solution may be measured approximately simultaneously.

The solution employed is not the one employed previously. The cell is one described in detail by Ives and Kingsbury (Phys. Rev. Nov. 1915, p. 319). It consists of a tank 1 cm. thick containing a solution of Copper Chloride, Potassium Chromate and Cobalt Ammonia Sulphate, together with a water tank 2.5 cm. thick to absorb all infra-red radiation.

Some of the values given for the luminous efficiency are as follows:

	Per cent
For the ordinary D. C. 110 volt solid carbon arc from...	0.34 to 0.97
For luminous yellow flame D. C. cored carbons.....	4.9 to 7.1
For luminous yellow flame arc A. C.....	4.1 to 8.3
For yellow flame, homogeneous carbons, A. C.....	11.5 to 22.5
For white flame, homogeneous carbons, A. C.....	6.8 to 7.4
For yellow flame, homogeneous carbons, D. C.....	18.4 to 19.3
For white flames, homogeneous carbons, D. C.....	9.5 to 13.0
For magnetite arc.....	5.1 to 7.4

All of the measurements were made in a horizontal direction from the arcs.

AN IMPROVED VISUAL ACUITY TEST OBJECT.

By Herbert E. Ives.

The visual acuity test object described by the writer some time ago,[1] and since employed in various pieces of research in physiological optics, consists of two superposed opaque line transmission gratings on glass. The spacing of the ruled lines is so fine that they are not separately visible at the appropriate working distance, but when the gratings are rotated with respect to each other about an axis perpendicular to their faces, parallel dark bands are seen, whose distance apart varies continuously with the angle of rotation. The angular separation of the bands when just visible is a direct measure of visual acuity.

The apparatus has recently been improved by the use of cross-line in place of single-line gratings. By this means the pattern, instead of being parallel bands, is made up of squares which expand or contract as the gratings are turned.

As the apparatus is constructed one cross-line grating is fixed in place, and either a single-line or cross-line grating may be used at will opposite to it, so that either parallel bands or squares are obtainable. The scale on which the angle of rotation of the gratings is read is divided to read directly in Snellen acuity units, in place of the clumsy fractions used by ophthalmologists as a consequence of the limitations of the alphabetical test charts.

THE THEORY OF TEMPERATURE MEASUREMENT BY THERMOCOUPLES OF GRADUATED SIZE.

By E. F. Kingsbury.

During the investigation of the temperatures assumed in a flame by mantles of various compositions, the author has made extensive use of Heræus platinum-platinum-rhodium couples of four different sizes. All is well known, when these are placed against the mantle they will assume different temperatures, depending upon their size, and when their diameters are plotted against the temperatures as abscissæ a continuous curve concave upward is obtained which, when extended to zero diameter, gives a limiting temperature to the mantle wall. Consistent results have been obtained yielding many smooth curves.

[1] "A Visual Acuity Test Object," Ives, *Electrical World*, April, 14, 1910, p. 939.

An explanation of the shape of these curves has been sought, assuming the couple and mantle surrounded by a film of gas through which the heat is conducted. An expression has been obtained that gives the shapes of these curves as obtained experimentally. It has been of assistance in showing the shape of the curves from zero to the smallest diameter.

The theory has also been extended to cover the temperatures assumed by mantles of various emissive powers when placed in a flame of known temperature. Here it has been assumed that the mantle is heated in much the same manner, except that outside the mantle the flame has been cooled in many cases at least nearly to the mantle temperature. This wall of flame protects the mantle from convected and conducted heat losses. The radiation efficiency calculated for the higher temperature mantles agrees with that actually measured experimentally. It has been found that the total emission per unit area per steradian is nearly a linear function of the temperature assumed in a flame. The theory in the light of the experimental curve is interesting as helping to explain the mechanism of a flame heating a mantle placed in it.

VISUAL DIFFUSIVITY.

By Herbert E. Ives.

In developing a theory to account for the behavior of the eye toward intermittent stimuli, the writer was led to postulate for visual mechanism a coefficient of diffusivity,[1] similar to the coefficient which holds for heat, electrical and all other forms of conduction through matter. By virtue of this finite diffusivity intermittent stimuli are greatly smoothed out before reaching the brain. From the phenomena of flicker it was deduced that this visual diffusivity must vary as the logarithm of the intensity of the stimulus and at a different rate for different colors.

The present study deals with a much simpler case than that of intermittent stimuli, namely that of single flashes of light. The physical illustration is that of instantaneously applied heat sources, a case which has been completely handled mathematically. According to this treatment it follows that if two simultaneously applied stimuli are transmitted by media of different diffusivity

[1] "Theory of the Flicker Photometer," Ives and Kingsbury, Philosophical Magazine, November, 1914, p. 708, April, 1916, p. 290.

they will be transmitted at different speeds. In the case of light this would mean that two differently colored simultaneous flashes, for instance red and blue, would be seen as occuring one after the other.

This idea was tested by means of red and blue glasses carried radially on a slowly rotating disc. It was found that the theory was very strikingly borne out, the blue image lagging after the red. The amount of this lag varies with the brightness as it should according to the theory.

On this theory the positive after-image is not a recurrent image, but the record as given by the retinal rods, delayed in transmission by the low diffusivity characteristic of this kind of vision.

A POLARIZATION FLICKER PHOTOMETER.

By Herbert E. Ives.

One of the most essential features of the flicker photometer is entire absence of mechanical flicker, as caused by the dividing edge between the two fields which are alternated. For this reason some means of eliminating this edge has long been desired.

From another standpoint, that of the theoretical treatment of flickering light, it is highly desirable to have an instrument in which the transition from one light to the other occurs according to some simple mathematical relation. The simplest relation is the sine curve, on which basis the theory of the flicker photometer has been handled by the writer and Mr. Kingsbury.[1]

The polarization flicker photometer recently constructed meets both these demands completely. It consists of a double image prism (Rochon or Wollaston prism), combined with a rotating Nicol prism. The double image prism forms two images of each half of the photometer field, one image being polarized in the horizontal, the other in the vertical plane. The horizontally polarized image of one field is superposed on the vertically polarized image of the other. On observing through the rotating Nicol prism, these two fields dissolve one into the other, following exactly the sine curve relation used in the theoretical work quoted.

Measurements have been made with this new photometer on the critical speeds for disappearance of flicker for various ratios of

[1] "The Theory of the Flicker Photometer," Ives and Kingsbury, Philosophical Magazine, November, 1914, p. 708, April, 1916, p. 290.

brightness of the two fields. The results are in complete agreement with the previously developed theory, accurate confirmation of which had not been found possible with the ordinary type of flicker photometer.

MEASUREMENTS OF BRIGHTNESS-DIFFERENCE PERCEPTION AND HUE-DIFFERENCE PERCEPTION BY STEADY AND INTERMITTENT VISION.

By Herbert E. Ives.

IN the theory of the flicker photometer as developed by the writer and Mr. Kingsbury [1] there figure two fractions, the brightness discrimination fraction, and the hue discrimination fraction. The former conditions the critical speed when two unequal fields of the same color are alternated, the latter when two equally bright fields of different color are alternated. These fractions are the least fractional parts appreciable by the ultimate receiving apparatus of the eye (presumably the brain), for successive impressions over the same path, and are neither susceptible of direct measurement. They can, however, be solved for from the equations of the theory, provided experimental constants can be obtained for stimuli following the simple sine curve variation of intensity which alone is susceptible of mathematical treatment.

The new polarization flicker photometer (see previous note) provides just such data, and has made possible the determination of the numerical values of these constants, and, what is more important, their relative values as compared to the same quantities for steady observation.

The value of the ultimate brightness discrimination fraction for intermittent light is found to be of the order of magnitude of one-fiftieth of one per cent. The hue discrimination fraction is of course dependent on the size of the color difference worked with. A complete determination of brightness and hue discrimination fractions, both steady and intermittent, for a certain large color difference, shows that the ratio of hue fraction to brightness fraction is about ten times larger for intermittent than for steady vision. *Herein lies the reason for the success of the flicker photometer,* for if these fractions maintained their steady relationship, the flicker photometer would have to be run at such speed, in order to eliminate color flicker, that no sensibility would be left.

[1] "Theory of the Flicker Photometer," Ives and Kingsbury, Philosophical Magazine, November, 1915, p. 708, April, 1916, p. 290.

THE FRANKLIN INSTITUTE

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, September 6, 1916.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 6, 1916.

MR. CHARLES E. BONINE *in the Chair.*

The following reports were presented for first reading:

No. 2675.—Sharples Super-Centrifuge.

No. 2676.—Eldred Electric Lamp Leading-in Wire.

The following report was presented for final action:

No. 2635.—Northrup's Electric Furnace and High Temperature Investigations. Elliott Cresson Medal to Dr. Edwin Fitch Northrup, of Princeton, N. J., adopted.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, September 13, 1916.)

RESIDENT.

MR. H. M. ELLIOT, Delong Hook and Eye Company, Station "J," Philadelphia, Pa.

MR. JOHN COOPER LYNCH, General Superintendent of Traffic, The Bell Telephone Company, 1631 Arch St. Philadelphia, Pa.

DR. PAUL STRAUS, Chemist, Lehigh Ave. and Edgemont St., Philadelphia, Pa.

NON-RESIDENT.

MR. WILLIAM H. CRAGO, Civil Engineer, Room 3525, 120 Broadway, New York City, N. Y.

DR. ALFRED B. HITCHINS, Research Chemist, in care of Ansco Company, Binghamton, N. Y.

MR. WALTER G. ROLAND, Brick Manufacturer, Oaks, Montgomery County, Pa.

MR. FREDERICK H. WAGNER, JR., Rogers Ave. and Pimlico Road, Station "E," Baltimore, Md.

MR. LEO WALLERSTEIN, Chemist, 171 Madison Ave., New York City, N. Y.

MR. NORMAN T. WHITAKER, Patent Lawyer, 22 Legal Building, Washington, D. C.

NECROLOGY.

Eckley Brinton Coxe, Jr., was born in 1873 and died on September 20, 1916. He was graduated from the University of Pennsylvania in 1893.

Mr. Coxe was greatly interested in archæology and financed several expeditions to Egypt during the past ten years.

He was a member of numerous social organizations and clubs. He was elected to membership in The Franklin Institute on September 13, 1899.

Mr. Lightner Henderson, 1515 Monroe Building, Chicago, Ill.
Mr. Thomas G. Hunter, 134 Poplar Ave., Wayne, Pa.
Mr. Mathias Pfatischer, 314 E. 3rd Ave., Roselle, N. J.

LIBRARY NOTES.

PURCHASES.

FLEMING, J. A.—Elementary Manual of Radiotelegraphy and Radiotelephony. 1916.

International Master Boiler Makers' Association, Proceedings. 1916.

MARTIN, G., SMITH, S., and MILSOM, F.—The Salt and Alkali Industry. 1916.

Moody's Manual of Railroad and Corporation Securities, vol. 17, Part 1, Railroad Section. Part 2, Industrial and Public Utilities Section. 1916.

MULLIKEN, S. P.—Method for the Identification of Pure Organic Compounds by a Systematic Analytical Procedure Based on Physical Properties and Chemical Reactions. Vol. 2. 1916.

NEWELL, F. H., and DRAYER, C. E., ed.—Engineering as a Career. 1916.

SUPINO, GIORGIO.—Land and Marine Diesel Engines. 1915.

GIFTS.

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British Columbia Minister of Mines, Annual Report, 1915. Victoria, 1916. (From the Minister of Mines.)

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Cambridge Water Board, Annual Report, April 1, 1914, to April 1, 1915. Cambridge, no date. (From the Board.)

Canadian Pacific Railway Company, Annual Report for the year ended June 30, 1916. Montreal, 1916. (From the Company.)

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Consolidated Gas Electric Light and Power Company of Baltimore, American Gas Centenary, 1816–1916. Baltimore, 1916. (From the Company.)

General Fireproofing Company, The Waterproofing Hand-Book, 1915, second edition. Youngstown, Ohio, 1915. (From the Company.)

Grand Rapids Public Library, Forty-fifth Annual Report, April 1, 1915, March 31, 1916. Grand Rapids, 1916. (From the Library.)

Haverhill Public Library, Forty-first Annual Report, 1915. Haverhill, Mass., 1916. (From the Library.)

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Institution of Civil Engineers, Minutes of Proceedings, vol. cci. 1915–1916. Part I. London, 1916. (From the Institution.)

Metropolitan Water and Sewerage Board, Fifteenth Annual Report, 1915. Boston, 1916. (From the Board.)

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Nebraska State Railway Commission, Eighth Annual Report, 1915. Lincoln, 1915. (From the Commission.)

New Mexico State School of Mines, Annual Register, 1915–1916, Announcements 1916–1917. Socorro, 1916. (From the School.)

New York State Department of Health, Thirty-fifth Annual Report, 1914, volumes i and ii. Albany, 1916. (From the Department.)

Pennsylvania Auditor General, Report, 1914. Harrisburg, 1916. (From the State Librarian.)

Pennsylvania Commissioner of Health, Eighth Annual Report, 1913, Parts I and II. Harrisburg, 1915. (From the State Librarian.)

Pennsylvania Department of Internal Affairs, Annual Report of the Bureau of Railways, 1915, Part IV. Harrisburg, 1916. (From the State Librarian.)

Powell, William, Company, Catalogue No. 10. Second Edition. Cincinnati, Ohio, 1911. (From the Company.)

Prest-O-Lite Company, Inc., Instruction Book on Oxy-Acetylene Welding and Cutting, Fourth Edition. Indianapolis, no date. (From the Company.)

Rio De Janeiro Museu Nacional, Archivos, vol. xix. Rio de Janeiro, 1916. (From the Museum.)

Salt Lake City Public Library, Annual Report, 1915. Salt Lake City, 1916. (From the Library.)

Smoke Prevention Association, Proceedings of the Tenth Annual Convention, 1915. Chicago, no date. (From the Association.)

Svenska Teknologforeningen, Ledamotsforteckning, July, 1916. Stockholm, Sweden, 1916. (From the Society.)

Tasmania Department of Mines, Geological Survey Bulletin No. 21, The South Heemskirk Tin Field, with maps and sections. Hobart, 1916. (From the Department.)

Taylor Instrument Companies, The H. & M. Division, Catalogues covering thermometers and temperature regulators. Rochester, N. Y. 1911–1916. (From the Company.)

University of Illinois, Illinois State Water Survey No. 12. Urbana, 1916. (From the University.)

University of South Carolina, Catalogue 1915–1916. Columbia, 1916. (From the University.)

BOOK NOTICES.

MECHANICAL TECHNOLOGY: Being a Treatise on the Materials and Preparatory Processes of the Mechanical Industries, by G. F. Charnock, M. Inst. C. E., M. Inst. Mech. E., Professor of Engineering, City of Bradford (Eng.) Technical College, 635 pages, illustrations, plates, tables, 8vo. New York, D. Van Nostrand, 1915. Price, $3.00.

This is a comprehensive text-book of 635 pages and 503 excellent illustrations, with complete Index of 13 pages and a list of books of reference.

The author modestly states in his preface: "It is hoped that the present work may form a useful guide for beginners and those with limited time at their disposal, enabling them to acquire some knowledge of the leading features of the work referred to."

A careful examination enables the reviewer to say that this hope is more than realized and the book is worthy of a place in any technical library. Part I covers: Production and Properties of the Chief Materials of Construction, viz.: Iron and Steel, Bessemer and Open Hearth Processes, Regenerative Furnaces, Gas Producers, Structure of Alloys, "Special" or Alloy Steels, Heat Treatment, Non-ferrous Metals, Properties and Uses of the Principal Varieties of Timber, Stone, Leather, Oils, etc., and Methods of Testing.

Part II.—Production of Castings of Iron and Steel, Defects and Remedies, Foundry Mixtures and Analyses, Die Castings, etc.

Part III.—Forging and Stamping. Production of Parts by Rolling, Wire Drawing, Manufacture of Tubes, Extrusion Processes, Manipulation of Sheet Metals by Flanging, Dishing, Drawing, Embossing, Coining, etc.

It is, of course, impossible in a book of this size, covering so many and diverse operations, to give many details that are more or less familiar to daily workers in metals, but, so far from this observation being in the nature of adverse criticism, the reviewer desires to express appreciation of the skill which has been shown throughout in balancing all parts of the work, avoiding skimping of necessary or important features, on the one hand, or redundancy on the other.

Naturally European practise is more thoroughly treated than American methods which differ in some respects, notably in foundry practise.

The paper and type, clearness of half-tone cuts and diagrams, with fine binding of the book, so that it remains open at any page, when laid flat upon a table, are all minor features worthy of commendation.

In a word this work is creditable alike to the author and publisher and will prove useful to the student and practical worker in metals.

A. E. OUTERBRIDGE, JR.

THE SCIENCE OF MUSICAL SOUNDS, by Dayton Clarence Miller, D.Sc., Professor of Physics, Case School of Applied Science. 286 pages, illustrations, plates, 8vo. New York, The Macmillan Company, 1916. Price, $2.50.

There have been many works on sound since the classical writings of Koenig, Rayleigh, and von Helmholtz, but none of the writers have made so exhaustive a study of sound as applied to music as has Professor Miller.

This work is based upon a series of eight lectures given at the Lowell Institute in 1914 under the title of "Sound Analysis," such changes being made as are required for presenting the subject to a reader instead of to an auditor.

Mathematical physicists, like von Helmholtz and Rayleigh, have found in the simple harmonic motions of the air in sound-waves a rich field for investigation and for the development of the formulæ descriptive of such motion.

Experimental physicists, like Koenig, have been able to apply their manipulative skill to the analysis of the formulæ and to determine their applicability to the characteristics of sound-waves.

It is an interesting fact that the early workers in the analysis of sound-waves expressed the results of their work in curves and their formulæ, and that these were directly applicable to the study of alternating currents of electricity, so that the early workers in the newer science found the principles governing it already investigated and formulated.

In order to make a record of the complicated vibrations that may be included in a musical tone, instruments of extreme delicacy must be used, and Professor Miller possesses that marvellous combination of inventive ability and mechanical skill that is necessary in devising such instruments and in compelling them to perform their function when built.

What is required in the study of sound-waves is an instrument that can respond to minute vibrations of great rapidity and that is capable of magnifying their amplitudes to any required extent.

Such an instrument is Professor Miller's Phonodeik, which responds to 10,000 complete vibrations, or 20,000 swings, per second and is capable of throwing the reflected beam of an arc light either upon a photographic plate for a permanent record, or upon a screen for showing to an audience. The vibrating beam alone gives a single line of light, but by combining with it a uniform progressive motion any wave-form, from the simple sine curve of a tuning-fork to the complicated curves obtained when a group of voices are singing, can be traced. The beauty and striking character of these curves can only be appreciated by seeing them flash across the screen in one of Professor Miller's lectures.

Other instruments of great precision used in the study of sound are the harmonic analyzer and the harmonic synthesizer. These are used in the mechanical proof of Fourier's Theorem, which is to the effect that any curve, having a wave-length l, can always be reproduced by combining the proper number of simple harmonic curves, each having a wave-length that is an aliquot part of l.

Any wave, after having been photographed by the phonodeik, may be analyzed by the harmonic analyzer, and when its component waves are thus found they can be recombined by the harmonic synthesizer and the original wave-form reproduced. An example of the accuracy of the reproduced curve is shown on page 127, where the synthesized curve is drawn over the original curve, thus showing how nearly exact is the reproduction.

Professor Miller's interest in the musical quality of sounds led him to make two flutes, one of silver and one of gold, for the purpose of studying

the difference in the quality of the tone produced. His analyses prove that the "tone from the gold flute is mellower and richer" than that from flutes of other materials, this being due to the existence of a longer and louder series of partial tones. His studies also prove that two organ pipes of the same internal dimensions will differ in pitch, depending upon their material.

Having technical skill, both as a physicist and as a musician, Professor Miller believes that there is a possibility of securing greater artistic effects in the mechanical production of music.

What is needed to secure this result is a closer coördination between the artistic production of musical sounds and their mechanical analysis.

No one with an appreciation of the physical sciences can read this book without interest: to the lover of music it reveals a vision of the intimate relation of music to the physical principles upon which it is based. What Professor Miller thinks of the latter can be seen by quoting his closing sentence, "No other art than music, through any sense, can so transport one's whole consciousness with such exalted and noble emotions."

GEORGE A. HOADLEY.

PUBLICATIONS RECEIVED.

Diseases of Occupation and Vocational Hygiene: Edited by George M. Kober, M.D., LL.D., Washington, D.C., and William C. Hanson, M.D., Belmont, Mass. 918 pages, illustrations. 8vo. Philadelphia, P. Blakiston's Son & Co. Price, $8.00.

United States Bureau of Mines: Bulletin 105. Black damp in mines by G. A. Burrell, I. W. Robertson and G. G. Oberfell. 88 pages, 8vo. Bulletin 116. Methods of sampling delivered coal and specifications for the purchase of coal for the government by George S. Pope. 64 pages, illustrations, plates, 8vo. Monthly statement of coal-mine fatalities in the United States, May and June, 1916. 2 pamphlets, 8vo. Washington, Government Printing Office, 1916.

United States Department of Agriculture: Bulletin No. 373. Brick roads by Vernon M. Peirce, chief of construction, and Charles H. Moorefield, senior highway engineer. 40 pages, illustrations, plates, 8vo. Bulletin No. 379. Dust explosions and fires in grain separators in the Pacific Northwest by David J. Price, engineer in charge of Grain Dust Explosion Investigations, Bureau of Chemistry, and E. B. McCormick, chief, Division of Rural Engineering, office of Public Roads and Rural Engineering. 22 pages, illustrations, plates, 8vo. Washington, Government Printing Office, 1916.

CURRENT TOPICS.

Mill Construction. C. E. Paul. (*Engineering Bulletin, National Lumber Manufacturers' Association*, No. 2, May, 1916.)—The term "mill construction" as commonly used is the name given to that type of building construction in which the interior framing and floors are of timber, arranged in heavy, solid masses and flat, smooth surfaces, so as to expose the least number of corners and to avoid concealed spaces which may not be reached readily in case of fire. A broader interpretation of the term includes the meaning given above, and adds the specification that fire shall pass as slowly as possible from one part of the structure to another. This means that each floor shall be separated from all others by incombustible walls or partitions, and by doors or hatchways which will close automatically in case of fire near them. Stairways, belt passages, and elevator shafts are encased or, preferably, located in fireproof towers. Openings in floors for passage of belts, etc., are either avoided or fully protected against passage of fire or water. The proper installation of an approved automatic sprinkler is of great importance. Ceilings in rooms where highly inflammable stocks are kept or where hazardous processes are followed should be protected by the use of fire-retardent material, such as plastering lead on wire lath or expanded metal. The ceiling should follow the lines of the timbers without an air-space between the two surfaces.

The "mill construction" type of building originated in the cotton and woollen mills of New England in the early days of that industry. Instances of buildings of the mill construction type are found in the early part of the nineteenth century, but no great prominence was given to this particular type of structure until the owners of a large number of these mills formed an organization, about the year 1835, for the mutual protection of their property from damage by fire. An instance of the durability of timber in properly built mill construction buildings is shown in the Warner mill in Newburyport, Mass. In this building heavy timber girders 45 feet long and spanning three bays have carried their load since the early fifties without signs of failure, and are said to be in as good condition to-day as when first installed.

Photographic Negatives upon an Opaque Support. Anon. (*Revue Scientifique*, vol. 54, No. 15, August 5, 1916.)—From time to time various efforts have been made to manufacture photographic plates with a support of paper of very uniform texture, with the object of reducing the cost and other objections of the usual glass or celluloid carrier. The insufficient regularity of texture and transparency of paper have so far, however, defeated the efforts of manufacturers to introduce paper for this purpose. A

method of overcoming this objection, proposed by F. Larajolli, consists in making the print, not by transmitted light, but by reflected light. The emulsion is supported upon a fairly heavy white paper, the back of which is coated with an opaque color. Halation is thus entirely avoided, while the white surface constitutes an efficient reflector. These "plates" are mounted and exposed in the camera in the same manner as the "film-pack." Development is controlled in the same manner as that employed with other papers in which the image is produced by the action of a developer. A special apparatus somewhat like the common type of enlarging camera is employed for printing, arranged with a source of illumination like that employed in lanterns for projecting opaque objects. The cost of such paper plates is said to be one-half that of glass plates and from one-third to one-quarter of celluloid films.

Deep Wells That Feel the Sea. ANON. (*U. S. Geological Survey Press Bulletin*, No. 284, August, 1916.)—In their investigation of the underground water resources of the Coastal Plain of Virginia the geologists of the United States Geological Survey have collected data relating to the many hundreds of artesian wells that yield excellent waters in large areas of the coastal region. Particular note has been made of the quantity and quality of the supply afforded by wells that give flows at the surface. The water of most of these wells is admirably adapted to household uses, though that of some of them contains enough mineral salts in solution to make trouble in boilers used for steam production.

The variation in flow exhibited by these wells with the rise and fall of the tide is of peculiar interest, the flow being notably greater at the flood than at the ebb tide. It is the general opinion among well drillers that practically all flowing wells near tidal rivers or inlets from open bays do feel the distant sea, but some of them so slightly that the variation in flow is not noticeable.

The geologist in charge of the ground-water investigations in Virginia states that changes in water level in wells, due to fluctuations in the height of the surface of some neighboring body of water, have been observed all over the world. It is customary to explain these changes by supposing a direct connection between the river, lake or bay, but in many places, as in eastern Virginia, such connection is clearly impossible, owing to the depth of the wells and the nature of the intervening beds, some of them dense, tough marls and clays. These beds, however, though they do not transmit water, nevertheless contain it, and as water is practically incompressible, any variation of level on the river or bay is transmitted to the well through the water-filled gravels, sands, clays and marls. When a porous bed is tapped by a well the water rises to the point of equilibrium and fluctuates as the hand of the ocean varies its pressure on the beds that confine the artesian flow.

Sources of Platinum. ANON. (*Engineering*, vol. cii, No. 2642, August 18, 1916.)—Russia had always been the source from which the bulk of the world's supply of platinum has been obtained. The main output comes from the Ural Mountains. During 1910, 175,720 ounces of crude platinum was secured, while in 1913 the quantity was 250,000 ounces and during 1914 about 241,200 ounces. The actual output is probably much greater, as a considerable quantity is sold without being officially recorded. The metal is found in placer deposits in several districts, of which the most important are: Tcherdin, Perm, North and South Ekaterinberg, and North and South Verkhotom. The output from these sources has been steadily increasing for a number of years. The richer placer deposits have been derived from the prolonged weathering of a variety of olivine which occurs in the Ural Mountains, in a somewhat narrow zone. They occur also along the mountain slopes in the river beds. The average yield is now under an ounce of platinum per ton of gravel; formerly it was more. The workers have now either to exploit poorer placers, or to develop richer ones in more remote situations which are not only more difficult of access but more troublesome to work, Prospecting has been carried on from time to time, but additional deposits are not readily found. Some of the districts have been worked for nearly eighty years. The Northern Urals have not yet been thoroughly explored, but olivine districts are known to occur there. Dredgers and excavators are now employed for working the deposits.

In Colombia, placer deposits have been extensively worked by the Spaniards since the sixteenth century; they contain both gold and platinum in the proportion of 900 per cent. of the former and 10 per cent. of the latter. Formerly only the gold was recovered and the platinum thrown away. The districts in which the bulk of the platinum is found are on the Pacific side of the Andes, in the valleys of the rivers Atrato, Aguendo, and San Juan. Both the platinum and the gold found in the placers have been eroded from veins in the rocks of the mountains, high up the water-shed. The output of crude platinum in Colombia is 15,000 ounces in 1913 and 17,500 ounces in 1914.

Placer mines yielding platinum occur in northern California and in southern Oregon; the metal is found there in minute, thin, flaky particles, and is always associated with black sands. It is also obtained from a copper-platinum-palladium ore, the product of a mine in Wyoming, and from a gold-platinum-palladium mine in Nevada. During 1912 the California output amounted to 603 ounces of crude platinum; for 1913 the combined output of California and Oregon was 483 ounces, and during 1914 it reached 570 ounces. Traces of platinum have also been found in British Columbia, a few miles from the village of Tulameen. The platinum is associated with chromite in mines worked for diamonds. It is also reported that platinum

deposits of considerable extent have been recently discovered in Spain. They are situated in the Ronda Mountains, about forty miles north of Gibraltar. These mountains are said to have the same geological structure as the Ural Mountains, but the formations of the Ronda section are much greater than the Russian. In the Rhine Provinces of Germany deposits have been discovered which may in the future yield a considerable output. Tasmania and New South Wales in 1914 produced 12,480 ounces. In 1913, 200 ounces of platinum were obtained from Borneo, Sumatra, and elsewhere.

Measuring the Pressure of Light. G. D. WEST. (*Proceedings of the Physical Society of London*, vol. xxviii, part v, August 15, 1916.)—The pressure of the radiation emitted by a carbon filament lamp at a distance of a few centimetres is sufficient to cause a microscopically measurable deflection of the end of a strip of gold or aluminum foil suspended in a closed test-tube. By this means the radiation pressure may be measured, and the results may be checked by a comparison with the energy density of the radiation as deduced from the initial rate of rise of temperature of an exposed blackened copper plate. Previous experiments were carried out in atmospheres of air and hydrogen, and at pressures extending from 76 centimetres to one centimetre of mercury. The present experiments deal with pressures from one centimetre of mercury down to the highest exhaustions that could be reached.

As the pressure is lowered certain gas-action effects make their appearance, but, inasmuch as there is no appreciable difference of temperature on the two sides of the strip, the effects are somewhat different from those that occur in the ordinary type of Crookes radiometer. When the surface of the strip is closer to one side of the containing vessel than to the opposite side, a deflection away from the closer side occurs, and the direction of the deflection is independent of the side of the strip upon which radiation falls. With symmetrically placed strip the deflection should be negligibly small. An explanation of these effects is suggested and a special type of radiometer is described. The nature of the residual gas in the tube does not seem to be very important, but it is found that the repulsive force acting on the strip increases with decreasing pressure until a maximum is reached at about 0.002 centimetres of mercury. With a further reduction of pressure a progressive decrease takes place. By symmetrical suspension and by the use of liquid air and charcoal, it is possible to so reduce the gas-action effect that measurements of the pressure of light of reasonable accuracy are again possible. Experiments on the pressure of light may thus be advantageously carried out at the highest vacua obtainable, or at pressures as far above 0.002 centimetre of mercury as convection currents will permit. The latter alternative is easier and leads to more consistent results.

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